Power plants layout

with

Gas engines
(Planning and Installation Notes)

06-2017
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Figures, drawings, diagrams and circuit diagrams within the handbook represent general information for the project planning. The relevant order documentation is binding for orders.

There is no revision service for the drawings of the installation guidelines. They will only be updated with the next edition of the installation guidelines.

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Foreword

The guidelines of this handbook are not operating instructions for the final machine user. Thus the guidelines are not user information as defined by DIN EN 82079-1 (IEC 82079-1), but fulfil a similar purpose, because their observance ensures the engine's operation and thus protects the end user from danger which could result from using the plant.

Operating safety and a long service life can only be expected from perfectly installed systems. This also allows maintenance work to be carried out simply and quickly. These guidelines provide information for mounting and give information about limit values to be observed.

The safety regulations, which are a component of the gensets and/or system documentation, must be complied with during layout, maintenance and operation of the systems.

The wide range of installation options does not allow for generally applicable and strict rules. Experience and special knowledge are necessary in order to ensure optimum installation of the gensets. The standards, directives and regulations listed have no claim to completeness. Therefore the local requirements must be investigated and duly taken into account in each individual case.

Therefore we recommend an installation consultation with Caterpillar Energy Solutions GmbH or an authorized sales partner during the planning stage.

Caterpillar Energy Solutions GmbH does not accept warranty claims and Caterpillar Energy Solutions GmbH is not responsible for damage or loss occurring from failure to comply with the information and instructions given in this handbook.

Your suggestions on how to enhance or supplement these guidelines are always highly appreciated.

Caterpillar Energy Solutions GmbH, VI-T1S, 2017-06
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Power plants layout

Chapter 1

Layout of gas engine-powered gensets
for combined power and heat generation at power plants

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1. **Layout of gas engine-powered installations for combined power and heat generation at power plants (CHPs)**

A gas engine-powered genset comprises a combustion engine, generator, coupling, base frame and mounting arrangement. The engine and generator are rigidly mounted on the base frame. This unit is described as a CHP genset and is used to generate electricity and heat.

A CHP module comprises a CHP genset and the following components:

- Cooling water heat exchanger
- Exhaust heat exchanger
- Exhaust silencer
- Exhaust gas cleaning system
- Fuel tank or gas supply
- Lube oil supply
- Monitoring system

A combined heat and power plant may comprise one or more CHP modules: the electrical switchgear with control system, the air supply system and the exhaust air system.

The basic principles, requirements, components, implementation and servicing of electricity generating sets are described in DIN 6280, Part 14 (see Fig. 1.1).

**Attention!**

It is not allowed to change any parts in the gensets, components and control cabinets which are delivered by the manufacturer.

To avoid EMC problems, the parts on the system side, e.g. frequency converters, must be connected with shielded lines in accordance with the manufacturer's specifications. See also Chapter 14 and 17.

1.1 **Types of use**

Depending on its use, the system may be primarily used to generate either electricity or heat.

1.1.1 **Heat-led operation**

In the case of heat-led operation, the demand for heat is the lead factor which determines the output of the CHP. To cover the demand for heat during peaks, the CHP may be supported by other heating systems.

1.1.2 **Electricity-led operation**

In the case of electricity-led operation, the demand for electricity is the lead factor which determines the output of the CHP.
1.1.2.1 Mains parallel mode

In mains parallel mode, the combined heat and power plant supplies consumers e.g. until the maximum electrical output is reached according to the rated power of the engine. Any further additional demand is covered from the mains power supply. During high-tariff periods, the gensets can be used to offset peak loads.

In the event of a mains fault, the combined heat and power plant can be operated in island mode.

1.1.2.2 Island mode

When operating in island mode, the combined heat and power plant supplies the power demand of the consumers by itself.

The gensets are required to supply the power for all connected consumers at any time of operation. This applies both to load switching and load shedding.

The switching system's load management has to ensure that the gensets are never overloaded. Load surges should not exceed the maximum permissible load steps as specifically determined for each genset type under any circumstances (refer to Chapter "Load steps"). This applies both to load switching and load shedding. The required switching power of the respective consumers is of particular consideration here, not the rated power (See also Chapter 15 "Island mode” and Chapter 16 "Load steps").

1.1.2.2.1 Back-up power operation

Taking due account of the appropriate additional measures required, the combined heat and power plant can also be used to provide a back-up power supply, covering the demand for power in the event of a network power failure as per:

- DIN VDE 0100-710 (IEC 60364-7-710)
- DIN VDE 0100-560 (IEC 60364-5-56)
- DIN EN 50172
- DIN VDE 0100-718 (IEC 60364-7-718)

The back-up power operation must be clarified and approved in each individual case. Not all gensets are capable of providing a back-up power supply as stated by the standards mentioned above. The engine-specific load steps must be adhered to.

The heat energy simultaneously produced by the combined heat and power plant should, if possible, be utilized (e.g. for heating or refrigeration), for which purpose heat accumulators should be employed where necessary. When providing a back-up power supply, heat dissipation must be guaranteed under all circumstances, if necessary with the aid of emergency cooling facilities and/or accumulators.
1.1.2.2.2 Black start

The black start is an emergency function of the gas gensets and should be used only for emergency situations. If a gas genset is "black-started", it starts without auxiliary drive power for prelubrication and cooling water pumps. The gas genset is started directly after the TEM demand contact has been closed. The cooling pumps start as soon as the auxiliary drive power supply is available. Furthermore, the gas genset will be started without prior leak monitoring of the gas control line.

The engines of the series TCG 2016/TCG 3016 and TCG 2020 are capable of black-starting. The engines of the series TCG 2032 cannot be black-started. (See also Chapter 15.7).

1.1.3 Operation dependent on the availability of combustion gas

With this type of operation, the lead factor is the available supply of combustion gas (e.g. landfill gas, sewage gas, biogas, etc.). In the case of multi-engine systems, gensets are switched on or off depending on the amount of gas available. For single engine systems, the engine power is adjusted to the available gas amount.

1.1.4 Dual gas operation

For special applications, the gas gensets can be equipped with two gases for the operation. If, for example, natural gas and sewage gas are available, it is possible to change over from sewage gas to natural gas if sewage gas is lacking. For the changeover between the two gases, the genset must be stopped.
Fig. 1.1
Definition and demarcation of CHP components as per DIN 6280-14

A Combined heat and power plant (CHP)
B CHP module
C CHP genset
1 Reciprocating pistons, internal combustion engine
2 Generator
3 Coupling and flexible mounting
4 Combustion air filter
   (Optionally installed separately from the engine)
5 Exhaust heat exchanger
6 Cooling water heat exchanger
7 Exhaust silencer
8 Exhaust gas cleaning system
9 Fuel tank or gas supply
10 Lube oil supply
11 Monitoring system
12 Switchgear with control system
13 Air supply system
14 Exhaust air system
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Chapter 2

Genset output

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2. **Genset output**

To plan the size of the genset, it is necessary to determine the demand for electricity and heat on the basis of annual consumption curves.

2.1 **Demand for heat**

The heat demand curve can be used to determine the size and number of gensets required for heat-led operation. However, with heat-led operation, it is essential to consider the generation of and demand for electricity. The choice of operating mode may lead to negative feed and/or to power being drawn from the mains.

2.2 **Demand for electricity**

The electricity demand curve is decisive in determining the demand for electricity in mains parallel operation. At the same time, it is necessary to investigate whether it is appropriate to split the total output between several gensets. For back-up power operation, in addition to the demand for electricity in mains parallel operation, the back-up power output must also be considered. A distinction must be drawn between "important" and "non-important" consumers and their permitted downtimes.

Not all consumers are connected or achieve their maximum current consumption simultaneously (simultaneity factor).

Some consumers purely consume real power, while others merely consume an apparent power output (power factor “cos phi”). Particular consumers, such as those with impact load characteristics or which make extreme demands in terms of constant voltage and frequency, must be taken into account.

Under special climatic mounting conditions (high altitude, high air temperatures and air humidity), the engine and generator are unable to produce their normal output (power reduction as per ISO 8528-1, DIN VDE 0530 and DIN EN 60034).

2.3 **Available fuel supply**

The genset output and number of gensets will be dependent on the available gas volume. The gensets must be operated only in the 50 – 100 % power range. For continuous operation, the power should be above 70%.
2.4 Provision of control energy

Gas engine gensets are usually designed for continuous operation. Plants that receive financial support within the framework of the EEG (German Renewable Energy Act) are operated in the way that is most economical for power input according to the EEG.

In an electric power supply system, generation and consumption of electrical power must always balance each other out, since power in an electrical supply system can only be stored with very high restrictions. Deviations between generation and extraction must be balanced using control energy.

Control energy is defined as energy that a network operator requires in order to balance out unexpected power fluctuations in their power grid. There are two different types of control energy here:

- Positive control energy
  In the event of an unpredicted increased power demand, positive control energy is necessary.
- Negative control energy
  When power production is above the current demand, current collectors must be switched on or power generators switched off temporarily.

There are three different qualities of control energy:

- Primary control energy
  Is required for quick stabilization of the mains within 30 seconds.
- Secondary control energy
  Must be fully available within five minutes.
- Tertiary control energy (minute reserve)
  Is used for the replacement of the secondary control energy, is to be consumed within a lead time and is retrieved for a period of at least 15 minutes at a constant height.

The amount of renewable energies is continuously increasing. Since wind and solar energy in particular are not permanently available, power generation from controllable plants is gaining ever greater significance. Gas engine gensets can meet these requirements of a flexible driving style. For biogas plants, the so-called flexibility premium was introduced in order to produce as much power as possible from renewable energies when the power demand is high.

For the gensets of CES, two operating modes are possible in flex operation:

- provision of the control energy in the part-load operational range
- starting from standstill (full power of the genset is used)

CES recommends operation in the part-load operational range, since this operation protects the genset the most. In the part-load operational range, all gensets of CES can provide control energy in the three abovementioned qualities.
The provision of control energy when starting from standstill is possible with the following restrictions:

- Up to four starts a day or max. 1000 starts a year
- Two hours minimum runtime after a start

The gensets of the series TCG 2016, TCG 3016 and TCG 2020 can be used when starting from standstill to provide secondary and tertiary control energy, those of the series TCG 2032 can only provide tertiary control energy.

Adjustments to the prelubrication and to the preheating of the gensets contribute to the reduction in wear with these operating conditions. Maintenance and servicing schedules specially aligned to flex operation guarantee a high availability of the gensets.

2.5 Performance data on the rating plates

In the case of a generator genset, the engine, generator and genset each have their own rating plate.

2.5.1 Rating plate of the engine

In the case of gas engines, the output SCN (continuous output, cannot be overloaded) is outlined according to DIN 3046-7. On the test bench, gas engines are run with natural gas. In the case of engines which are run with other types of gases in later operation, the output for the type of gas is additionally outlined on the rating plate. The type of gas is specified after the output description.

For example, the following power outputs can be indicated on the rating plate:

SCN n: continuous output during operation with natural gas; n means natural gas; the power output is run on the test bench.

SCN b: continuous output during operation with biogas; b means biogas.

Further extensions may be:

m mine gas
s sewage gas
l landfill gas

2.5.2 Rating plate of the generator

The rating plate of the generator lists the apparent power of the specific type according to IEC 60034-1 (DIN EN 60034-1) and the power factor (cos Phi) of the generator. The specification is given in kVA (Kilo Volt-Ampere), the power factor is dimensionless.
2.5.3 Rating plate of the genset

The electric rated power of the genset is given on the rating plate. The name of the power category is outlined according to ISO 8528-1. The output is given in KWel (Kilowatt electric).
Gensets with gas engines are designed for continuous operation; therefore, the genset rating plate shows the power category COP (continuous power of the genset).
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Chapter 3

CHP genset

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3. CHP genset

3.1 Genset design

Gensets comprise the following main components:

- Gas engine
- Generator
- Torsionally flexible coupling
- Base frame
- Flexible bearing elements

In the TCG 2016, 2020 and 2032 series, engine and generator are linked by a torsionally flexible coupling and rigidly mounted to the base frame. The base frame is mounted to the foundation by flexible bearing elements.

In the TCG 3016 series, the engine has a fixed connection to the generator via a flange housing, the torque transmission from the engine to the generator is also assumed by a torsionally flexible coupling. The engine/generator unit connected via the flange housing is elastically mounted on the base frame with rubber elements. The base frame is installed rigidly on the genset foundation.

All flexible connections for the operating media are installed on the genset. Auxiliary drives such as prelubricators and lube oil level monitors are mounted to the base frame.

Preheating must be provided for every engine. Dependent on the design of the system, this may be installed either at the genset or in the system.

3.2 Genset

3.2.1 Engine monitoring and cabling

The gas engine is equipped with sensors for monitoring and control purposes. The sensors are wired to a multifunction rail at cylinder rows A and B. Bus cables run from each multifunction rail to the TEM system (TEM see Chapter 14.1). At the engine, all parts needing to be grounded are connected to the copper rail. This rail must therefore be connected to the earthing system of the switchgear. An overview of the monitoring facilities is shown in the following engine drawings.
Fig. 3.1a Engine TCG 2016 V08 C, V12 C and V16 C – Sensor arrangement

1. Mixture temperature sensor before exhaust turbocharger
2. Coolant temperature sensor
   (low-temperature circuit, inlet)
3. Ignition coil, one ignition coil for every cylinder
4. Flywheel sensor – installation location depending on version
5. Starter relay
6. Starter
7. Knock sensor, one sensor for every two cylinders
9. Lube oil level sensor
10. Camshaft sensor
11. Crankcase pressure sensor
12. Stepper motor gas-air mixer
Fig. 3.1b Engine TCG 2016 V08 C, V12 C and V16 C – Sensor arrangement

1. Multifunction rail cylinder row B
2. Charging mixture temperature sensor after intercooler in the TEM system parameter receiver
3. Combustion chamber temperature sensor, one sensor for every cylinder
4. Coolant temperature sensor (high-temperature circuit inlet)
5. Prelubrication pump
6. Lube oil temperature sensor
7. Lube oil pressure sensor
Fig. 3.1c Engine TCG 3016 V12 – TPEM components and sensor arrangement

1. TPEM Control Unit (TPEM CU)
2. Coolant temperature sensor (low-temperature circuit, inlet)
3. Gas mixer position proximity switch
4. TPEM Connection Box
5. Starter relay
6. Starter
7. Knock sensor, one sensor for every two cylinders
8. Control unit - gas mixer
9. Stepper motor gas-air mixer
10. Coolant temperature sensor (high-temperature, outlet)
11. Coolant pressure sensor (high-temperature, outlet)
12. Lube oil level sensor
13. Camshaft sensor
14. Coolant temperature sensor (high-temperature, inlet)
15. Mixture temperature sensor before exhaust turbocharger
16. Receiver pressure sensor
Fig. 3.1d Engine TCG 3016 V12 – TPEM components and sensor arrangement

1. Ignition coil, one ignition coil for every cylinder
2. Spark plug, one spark plug for every cylinder
3. Combustion chamber temperature sensor, one sensor for every cylinder
4. Lube oil pressure sensor
5. Lube oil temperature sensor
6. Flywheel sensor
7. Differential pressure sensor - throttle valve
8. Control unit – throttle valve / wastegate (only for V16)
9. Starter relay
10. Throttle valve
11. Receiver temperature sensor
Fig. 3.2a Engine TCG 2020 V12(K) and V16(K) – Sensor arrangement

1 Coolant temperature sensor before intercooler
2 Knock sensor, one sensor for every cylinder
3 Combustion chamber temperature sensor, one sensor for every cylinder
4 Starter
5 Starter relay
6 Crankcase pressure sensor
7 Lube oil level sensor
8 Prelubrication pump
9 Lube oil pressure sensor
10 Camshaft sensor
11 Multifunction rail cylinder row A
12 Proximity switch gas-air mixer
13 Intake air temperature sensor
   V16 engine
14 Intake air temperature sensor
   V12 engine
15 Ignition coil, one ignition coil for every cylinder
Fig. 3.2b Engine TCG 2020 V12 and V16 – Sensor arrangement

1. Multifunction rail cylinder row B
2. Coolant temperature sensor (engine outlet)
3. Mixture temperature sensor
4. Coolant temperature sensor (engine inlet)
5. Lube oil temperature sensor
6. Lube oil pressure sensor
7. Knock sensor, one sensor for every cylinder
8. Combustion chamber temperature sensor, one sensor for every cylinder
9. Flywheel pulse sensor
10. Ignition control unit
11. Actuator
12. Stepping motor gas-air mixer
13. Ignition coil, one ignition coil for every cylinder
14. Exhaust turbocharger speed sensor
15. Exhaust turbocharger temperature sensor
Fig. 3.3a Engine TCG 2020 V20 – Sensor arrangement

1  Exhaust turbocharger temperature sensor
2  Intake air temperature sensor
3  Ignition coil, one ignition coil for every cylinder
4  Starter relay
5  Combustion chamber temperature sensor, one sensor for every cylinder
6  Knock sensor, one sensor for every cylinder
7  Crankcase pressure sensor
8  Camshaft sensor
Fig. 3.3b Engine TCG 2020 V20 – Sensor arrangement

1. Exhaust turbocharger speed sensor
2. Coolant temperature sensor (engine outlet)
3. Mixture temperature sensor
4. Coolant temperature sensor (engine inlet)
5. Lube oil temperature sensor
6. Lube oil pressure sensor
7. Knock sensor, one sensor for every cylinder
8. Combustion chamber temperature sensor, one sensor for every cylinder
9. Actuator
10. Flywheel pulse sensor
11. Coolant temperature sensor before intercooler
12. Ignition control unit
13. Proximity switch gas-air mixer
14. Stepper motor gas-air mixer
Fig. 3.4a Engine TCG 2032 V12 and V16 – Sensor arrangement

1. Coolant temperature sensor (high-temperature circuit inlet)
2. Proximity switch gas-air mixer, one switch for each gas-air mixer
3. Coolant temperature sensor (high-temperature circuit outlet)
4. Mixture temperature sensor, one sensor for each gas-air mixer
5. Stepping motor gas-air mixer, one stepping motor for each gas-air mixer
6. Depending on version – Base bearing temperature sensor
7. Multifunction rail cylinder row A
8. Camshaft sensor
9. Crankcase pressure sensor
10. Electric pump for pre-heating unit (coolant)
11. Electric pre-heater for coolant and lube oil
12. Electric pump for pre-heating unit (lube oil)
Fig. 3.4b Engine TCG 2032 V12 and V16 – Sensor arrangement

1. Lube oil temperature sensor
2. Start backup for engine turning device
3. Solenoid valve for compressed air starter
4. Flywheel sensor – installation location depending on version
5. Multifunction rail cylinder row B
6. Charging mixture temperature sensor, one sensor each for A and B side

V12 engine: between cylinders A4 and A5 as well as in front of B6
V16 engine: between cylinders A6 and A7 as well as in front of B8
Fig. 3.4c Engine TCG 2032 V12 and V16 – Sensor arrangement

1. Exhaust turbocharger speed sensor
   One sensor for every exhaust turbocharger
2. Actuator
3. Coolant temperature sensor (high-temperature circuit inlet)
4. Lube oil level sensor
5. Lube oil pressure sensor
   (Lube oil pressure before lube oil filter)
6. Coolant temperature sensor (low-temperature circuit, inlet)
7. Charging mixture pressure sensor A side, intercooler – depending on version
Fig. 3.4d Engine TCG 2032 V12 and V16 – Sensor arrangement

1. Flywheel sensor – installation location depending on version
2. Lube oil pressure sensor (lube oil pressure after filter)
3. Ignition coil, one ignition coil for every cylinder
4. Ignition control unit
5. Combustion chamber temperature sensor, one sensor for every cylinder
6. Knock sensor, one sensor for every cylinder
7. Charging mixture pressure sensor, one sensor each for A and B side
3.2.2  Genset examples

Figures 3.6 to 3.9 illustrate gensets with gas engines of the series 2016, 3016, 2020, 2032.

Binding genset dimensions are contained in the contract-specific genset drawing.
Fig. 3.5a Engine TCG 2016 V16 C with Marelli generator MJB 450 MB 4
Genset weight approx. 8450 kg (transport)
Fig. 3.5b Engine TCG 3016 V16 with Marelli generator MJB 450 MB 4
Genset weight approx. 6800 kg (transport)
Fig. 3.6 Engine TCG 2020 V16 with Marelli generator MJB 500 LA4
Genset weight approx. 13320 kg (transport)
Fig. 3.7 Engine TCG 2020 V20 with Marelli generator MJB 560 LB 4
Genset weight approx. 17900 kg (transport)
Fig. 3.8 Engine TCG 2032 V16 with Marelli generator MJH 800 MC6
Genset weight approx. 51400 kg (transport)
3.3 Generators

3.3.1 General

The types used as standard are brushless synchronous generators, which, depending on the application, may be suitable for mains parallel and/or back-up power mode.

Depending on output and the available mains supply, 400 V to 690 V three-phase generators or 4.16 kV to 13.8 kV medium-voltage generators are used as standard. Depending on the specific project, the implementation of further voltage levels can be checked.

The efficiencies of the generators are between 95.0 % and 98 % at full load, depending on the size and displacement factor cos(\(\phi\)).

Thus, for example, a 494 kVA generator with a power factor of cos(\(\phi\))=0.8 has an efficiency level of 95.5 % and a 5336 kVA medium-voltage generator with a power factor of cos(\(\phi\))=0.8 has an efficiency level of 97.2 %. If the generator is operated at a power factor of cos(\(\phi\))=1, efficiency is increased by approx 1-1.5 %.

Operation at partial load and deviation between the mains voltage and generator rated voltage also have an effect on the efficiency.

As per DIN VDE 0530 / IEC 60034, the generators are designed for an ambient temperature of 40 °C and an installation altitude up to 1000 m. At higher ambient temperatures or higher altitude, the output must be reduced in accordance with the manufacturer's specifications.

All generators can be used continuously at full active power output in the frequency range fn +/- 2 % fn for displacement factors of 0.8 overexcited up to 1. The cos(\(\phi\)) at the network connection point can therefore be improved during mains parallel operation if the generators are used for reactive power compensation. For corresponding local or country-specific requirements in the network connection rules, generators are used that can be continuously operated at full active power output and in the frequency range fn +3 % fn / fn - 5 % fn in the displacement factor range of 0.8 overexcited to 0.95 underexcited. The various requirements at the connection point here are always to be considered for the design. Generators must be specially designed for use outside the specified range.

The max. permissible unbalanced load for the generator must be taken into account. (According to DIN EN 60034 the upper limit for negative-sequence system / rated current = 8 %).
Fig. 3.9 Generator
3.3.2 Generator control

The generator controller serves for adjusting the voltage in island mode and the power factor (or the reactive power) in mains parallel mode by corresponding adjustment of the exciter current. The exciter system is designed without brushes for all generators. When using a digital generator controller (e.g. Marelli MEC-100) it is possible to specify external set values for the controller. The generator controller is usually integrated in the generator terminal box. The principle function of the voltage regulator is shown in Figure 3.10.

Fig. 3.10 Generator control system (for example with supply from an auxiliary winding)

1  External set value
2  Generator controller
3  Stator
4  Exciter field
5  Current measurement
6  Voltage measurement
7  Rotor
8  Primary field
9  Diode wheel
G1  Main machine
G2  Exciter
3.3.2.1 General function of the generator control system

The supply to the generator controller can be realized in various ways: either from an auxiliary winding directly / via a voltage transformer from the stator terminals or via a permanent magnet generator (PMG).

The principle functionality of the controller is the same in all cases. The controller affects the exciter current of the brushless exciter machine, which is designed as an external pole machine. The rotor of the exciter machine is mounted on the shaft of the main machine and supplies a three-phase voltage system proportional to the exciter field current. This is in turn rectified via the diode bridge that rotates with it. The output direct current of the diode bridge is supplied to the rotor winding of the main machine. The reaction to an external voltage or power factor set value results in a corresponding change to the exciter field current and hence the indirect effect of the primary field current.

3.3.2.2 Set value specification

If a digital generator controller (e.g. Marelli MEC-100 or Basler DECS-100) is used, the set values for the corresponding control mode must be either parameterized in the controller or an external specification (e.g. via a 4...20 mA analog signal) is to be realized via a remote technical connection. If an analog generator controller is used, the set value is to be specified via a set value adjuster. The generator controller measures the generator terminal voltage three-phase either directly or via a voltage transformer as well as the generator current single-phase via a current transformer and calculates the actual value of the control variable from this. In island mode, this is the voltage; in mains parallel mode, it is the reactive power or the power factor. The corresponding exciter field current to be output is calculated via a comparison between the set and actual value.

3.3.3 Generator protection

To protect the generators, at least monitoring devices marked in ISO 8528-4:2005 as required ("REQ") must be used.

These monitoring facilities are not included in the TEM system and must be performed externally. In addition to the generator synchronization, the synchronization and protective unit "easygen", which can be supplied by Caterpillar Energy Solutions, also contains functions for generator protection.

In the TPEM system the protective functions of the multifunctional relay (MFR) are adopted. The MFR is installed in the TPEM Control Cabinet as standard. For more on this see also Chapter 14.3.

The international standard ANSI/IEEE C37.2 allocates fixed numbers for functions, including the generator protection functions. Table 1 shows the generator protection functions.
Table 1: Generator protection functions

<table>
<thead>
<tr>
<th>Number as per ANSI/IEE C37-2</th>
<th>Designation</th>
<th>Easygen</th>
<th>TPEM MFR in TPEM CC</th>
<th>LV plants</th>
<th>MV plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>59/27</td>
<td>Overvoltage / undervoltage</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>81 O/U</td>
<td>Overfrequency / underfrequency</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>32</td>
<td>Overload</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>32 R/F</td>
<td>Reverse load / reduced load</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>47</td>
<td>Voltage asymmetry</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>46</td>
<td>Current asymmetry</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>50</td>
<td>Defined overcurrent</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>51/51V</td>
<td>Inverse time overcurrent monitoring</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>87G</td>
<td>Generator differential protection</td>
<td>x</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>50N/51N</td>
<td>Stator earth fault protection</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

In addition to the protective functions stated in Table 1, all generators supplied by CES are equipped with the following sensors:
- Temperature sensors for winding temperature
- Temperature sensors for generator bearing temperature

Depending on the design of the plant, these sensors can be integrated into the TEM/TPEM control or into the plant control (HAS). Monitoring of the winding and bearing temperature should always be carried out.

### 3.3.4 Earthing

The protective earth conductor (PE) and the protective equipotential bonding must be considered for the earthing.

The protective earth conductor has the task of diverting the fault current to earth in the event of a short-circuit. The connection is made at the generator housing. A bore hole is provided for this on each of the generator feet on the non-drive side (see Figure 3.12). The protective earth conductor is routed from the generator housing to the main earth electrode of the plant. It must be ensured that the routing is short-circuit-proof. The connection of the protective earth conductor should be realized as specified in Figure 3.11. The following is to be observed: The area at the connection must be free of paint and dirt. The tooth lock washers serve to protect the screw connection from becoming loose. According to the latest insights, it must be ensured that the tooth lock washers are realized with so-called stop teeth.
Fig. 3.11 Recommended screw connection of a protective earth conductor

1 Nut
2 Tooth lock washer
3 Washer
4 Housing
5 Tooth lock washer
6 Screw
7 Cable lug
8 Protective earth conductor

The cross section of the protective earth conductor is calculated via the following formula:

\[ S = \frac{I_k''}{k} \times \sqrt{t} \]

- \( S \) Cross section in \( \text{mm}^2 \)
- \( I_k'' \) Initial short-circuit direct current in A
- \( k \) Coefficient that depends on the conductor material (e.g. 143 for copper)
- \( t \) Time in which the fault current flows over the conductor

So as not to have to consider every case, the recommendation for the cross section of the protective earth conductor at low voltage is 240 \( \text{mm}^2 \) for the gensets of series TCG 2016/3016 and 300 \( \text{mm}^2 \) for the gensets of series TCG 2020. In the case of medium-voltage gensets, a cross section of 95 \( \text{mm}^2 \) can be used for all series. This data only refers to copper conductors, a calculation must be conducted for other materials.

The protective equipotential bonding serves as protection upon indirect contact. It ensures that the potential difference between metallic parts always remains below 50 V. Thus no dangerous shock currents flow in the event of a fault if a person comes into contact with the genset. The protective equipotential bonding is routed between all metallic parts and the main equipotential bonding. The generator is connected to the genset base frame via two earthing strips. The engine, coupling protection and further metallic parts are also connected to the frame via copper conductors. The frame must be routed to the main equipotential bonding.
at two diagonally opposite corners each with a copper conductor (min. 70 mm$^2$). Likewise, all metallic lines (gas, water etc.) as well as all further metallic parts in the genset room must be integrated in the equipotential bonding. The cross sections depend on whether a fault current can issue from the relevant part or not and must be adapted to the conditions on site. The local power supply company rules or safety regulations must be observed in order to ensure that the genset earthing is correct.

Fig. 3.12 Protective earth conductor connection to the generator

1 Connection for the PE
2 Protective equipotential bonding
Power plants layout

Chapter 4

Requirements for genset installation

06-2017
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4. Requirements for genset installation

4.1 Genset room

Having carefully selected and established the output of the genset, there are a series of preconditions which must be fulfilled by the client to achieve a safe, low-maintenance, and fault-free operation. The most important questions associated with the setup and installation of the genset must therefore be clarified at the time when buildings intended to house the energy generation units are being planned. Alterations and special solutions introduced at a later date are generally expensive and often unsatisfactory. Right from the start, consideration should be given to possible future expansion.

4.1.1 Site

The planning process begins with the selection of the site at which to set up the genset. In order to minimize losses in the transmission of energy to the consumer, it makes practical sense to arrange the genset in the vicinity of the consumer. However, requirements in terms of noise and vibration often lead to gensets being set up far away from residential properties.

Where a building is reserved for energy generation, the problems of ventilation, vibration damping, fuel supplies and storage, and also of bringing in and providing access to the genset are generally easier to resolve. Genset rooms inside large buildings such as department stores, hospitals and administration buildings should be located as near as possible to an outside wall, so there is no difficulty in drawing in and discharging air for cooling and ventilation. The genset room can be designed at ground level, below ground, or in the case of smaller gensets, even on one of the upper floors.

The choice of building materials must take account of the need for sound and vibration damping.

4.1.2 Requirements for the genset room

The genset room should be of adequate size. Aside from the added complication of operation and maintenance, the problem of ventilation in small rooms is also not easy to resolve. For the TCG 2016, 3016 and 2020, a clear space of approx. 1 m in width should, under all circumstances, be allowed for all round the genset, increasing to approx. 2 m in width for bigger engines. Care must be taken to ensure that the starter batteries are installed as close as possible to the electric starter. For installations with engines TCG 2032, it is necessary to provide a free area (pre-assembly area for the cylinder units) of 2 m by 5 m suitable for acceptance of heavy weights. Preferably, this area should be arranged close to the engine in order to achieve access by the same crane both for the pre-assembly area and the engine itself.

Furthermore, the size of the room will be determined by the other components to be installed, such heat utilization unit, switchgear, gas control line, fuel tank, lube oil tank, batteries, exhaust line and silencer. The silencers for the inlet and exhaust air also require enough available room. It is essential to design large
enough openings to bring in the genset, and to ventilate the system (see Chapter 5, Engine room ventilation).

No genset room should be without permanently installed lifting gear (crane), the load-bearing capacity of which corresponds to the heaviest single item in the room. It must, however, in all cases be guaranteed that, when carrying out maintenance work, depending on the engine type, e.g. pistons, con-rods, cylinder heads or even a complete engine can be lifted. Both assembly and subsequent maintenance can then be carried out more quickly and more practically.

The genset room should be of sufficient height to allow pistons and connecting rods to be withdrawn upwards, taking into account the lifting gear. The size of the room must permit work to be carried out unobstructed at all points around the genset and there must be space to park individual genset components and spares.

Together with the planning of the genset room, the elastic mounting, the design of the foundation block, the pipe and cable work must be clarified. Also to be considered in the early stages of planning is the implementation of any special noise protection and anti-vibration insulation measures.

For smaller genset power outputs, the genset and the switchgear can generally be set up in one room. For larger plants, it may be more practical to install the switchgear in a separate, sound-proofed operating room.

When planning the genset room, consideration must also be given to the transport route, so that if necessary, an engine or generator can be dismantled and reinstalled (floor loading and space available).

The example in Figure 4.1 illustrates a practical and proven genset installation.

If access to the genset and its components is heavily restricted due to the engine room not being designed large enough, the manufacturer may claim additional costs when performing maintenance or repair work within the scope of the manufacturer’s warranty.

When operating and when performing maintenance work on the genset, lube oil and/or coolant can enter the genset room under certain circumstances. Restraining devices must be provided in the genset room drainage system and reliably prevent environmental damage from these materials.
Before detailed planning work starts, the manufacturer would also assist prospective clients with further documentation on standard installations. For major planning tasks, construction or draft construction drawings are requested by us.

4.2 Foundation and vibration damping

In the case of gensets with piston engines, gravity forces and moments of inertia cannot, in all cases, be completely balanced. The transmission to the foundation of the vibration and noise thus created can be significantly reduced by the use of elastic mountings. When installing gensets, the elastic mounting elements must therefore always be provided between the base frame and the foundation block.

4.2.1 Foundation block

For the base of the foundation, which must be implemented with special care, it is recommended that a soil investigation be carried out by an expert. The costs for this bear no relation to the expense involved in the subsequent work required, if, for example, it is found that vibration is being transmitted to the surrounding area.

There must be no groundwater veins either beneath or in the vicinity of the foundation block, as these can transmit vibrations over very long distances. This also applies to a high groundwater level which leads to
stronger transmission of vibration than occurs in dry ground. Depending on local conditions, the foundation block may have to be set on a sole plate or pilework.

Sinking and basing the foundation are in any case the responsibility of the construction company or architect. The latter must assess the load-bearing capacity of the soil and determine the solidity of the foundation block by specifying the requisite concrete mix and reinforcements to suit the local conditions.

For calculation purposes, clients will be provided with data on the foundation load imposed by the genset and the natural frequencies of the elastic bearings.

The implemented foundation block should not have any contact with base walls of the building or the floor for the above reasons. The gap between the foundation block and the floor can be sealed with an elastic material. To accept the elastic bearing elements, the surface of the foundation must be horizontal and disked, without being smoothed with a trowel. The foundation surface must be flat to a tolerance of max. ±2 mm. It is not permissible to mount the genset on tiles, pavement or any similar surface.

### 4.2.2 Elastic bearing

In order to insulate the genset as far as possible from the foundation in terms of vibration and structure-borne noise, steel spring bearing elements are used. These bearing elements reduce the transmission of dynamic forces to the foundation. The insulation of low frequencies in buildings is of great importance. This is also achieved with a soft steel spring bearing support. Structure-borne noise insulation is guaranteed by means of reflection from the base plate of the bearing, thanks to the insulation effect of the steel / rubber plate arrangement.

The elastic bearing must be recalculated for each application. The natural frequency of the system constituted by the genset / elastic bearing must be sufficiently far below the operating speed of the genset.

Insulation levels of approx. 88 - 98 % are achieved with the bearing elements used.

The spring elements which are used in gensets TCG 2016, 2020 and TCG 2032 can be adjusted in height over a certain range. They have to be properly adjusted; meaning the load on each element has to be equal. A wrong setting of the spring elements leads to their destruction on a long term basis and the oscillations cannot be isolated anymore. Spring elements can compensate unevenness of the foundation only to some extent. Due to an uneven load, too great an unevenness of the foundation and a wrong setting of the spring elements lead to the deformation of the genset's base frame. As a consequence, the alignment between the generator and the engine is no longer efficient. This can result in an incalculable destruction of the components.

In the TCG 3016 series of gensets the engine and generator are connected rigidly via a flange housing. The engine/generator unit is elastically mounted on the base frame with rubber elements.

### 4.2.3 Uneven foundation surfaces and foundation inclines

As mentioned in the previous paragraph, it is absolutely essential to attain the desired vibration isolation that all spring elements are equally loaded or have the same deflection. It is therefore recommended that you check the foundation evenness before installing the genset and, if necessary, provide washers below the
spring elements before lowering the genset into place. The thickness of the panels must be adapted to the required height compensation at the relevant spring element. Caterpillar Energy Solutions provides suitable panels in the thicknesses 1.2 and 5 mm for the relevant bearing types. The height adjustment of the bearings themselves is then only utilized for the fine alignment of the genset.

The procedure for ascertaining the foundation evenness and determining the washers that might be required is a component of the customer documentation.

4.2.4 Assessing vibrations

DIN ISO 8528-9 (ISO 8528-9) must be applied for gensets. This standard deals with the measurement and evaluation of the mechanical vibrations in electricity generating units with reciprocating piston combustion engines.

4.2.5 Cable and pipe ducts

Cooling water and exhaust pipes can be laid in ducts beneath the floor. The requisite dimensions must be adapted to the size of the pipes and to local conditions.

In general, care must be taken to ensure that ducts for pipes and ducts for cables are implemented separately from one another, whereby a further distinction must be drawn between power cables, control cables and signal cables. Ducts are laid with a fall leading away from the foundation block, with drains fitted with oil separators provided at the lowest points. The ducts can be covered with treadplate or grilles. Ducts and covers must always be provided by the client.

4.3 Noise issues

Since the acoustic requirements imposed by various laws and regulations on the installation of gensets with combustion engines are constantly increasing, a brief reference is appropriate here to the contexts and possible solutions to noise problems.

Noise sources mainly include the combustion noise of the engine, mechanical engine noises and the air intake and exhaust noises from the engine. The fans, pumps and other auxiliary drives can also be the cause of nuisance noise.

Too high air speeds can also cause noises (see Chapter 5.5 Planning notes).

There is nothing that effective resources can do to reduce the source of noise themselves. Thus most measures to mitigate noise are directed towards reducing the transmission of noise outside of the genset room.

4.3.1 Acoustic dependencies

Noise is made up of pressure waves of varying frequencies. All measurements of noise are thus frequency dependent pressure measurements. Lower-frequency noises are more easily tolerated by human beings
than those of higher frequencies. Sound waves above 16,000 - 20,000 Hertz, on the other hand, are generally beyond detection by the human ear.

The need to compare the loudness of sound events at different locations has led to the development of objective measuring procedures. Assessments are conducted in accordance with specific frequency curves, as defined in DIN EN 61672-1 and DIN EN 61672-2. This involves analysis curves A, B, C and D (Tab. 4.1). The assessment curves replicate in a somewhat simplified manner the frequency response of the ear to narrow-band noises. Curve A applies to the low-volume range, Curves B and C cover the range of loud and very loud noises. D applies to aircraft noises.

**Table 4.1**

<table>
<thead>
<tr>
<th>Frequency Hz</th>
<th>A dB</th>
<th>B dB</th>
<th>C dB</th>
<th>D dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.5</td>
<td>-39.4</td>
<td>-17.1</td>
<td>-3.0</td>
<td>-16.5</td>
</tr>
<tr>
<td>63</td>
<td>-26.2</td>
<td>-9.3</td>
<td>-0.8</td>
<td>-11.0</td>
</tr>
<tr>
<td>125</td>
<td>-16.1</td>
<td>-4.2</td>
<td>-0.2</td>
<td>-6.0</td>
</tr>
<tr>
<td>250</td>
<td>-8.6</td>
<td>-1.3</td>
<td>0.0</td>
<td>-2.0</td>
</tr>
<tr>
<td>500</td>
<td>-3.2</td>
<td>-0.3</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1000</td>
<td>0.0</td>
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<td>0.0</td>
</tr>
<tr>
<td>2000</td>
<td>1.2</td>
<td>-0.1</td>
<td>-0.2</td>
<td>8.0</td>
</tr>
<tr>
<td>4000</td>
<td>1.0</td>
<td>-0.7</td>
<td>-0.8</td>
<td>11.0</td>
</tr>
<tr>
<td>8000</td>
<td>-1.1</td>
<td>-2.9</td>
<td>-3.0</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Engine noises are normally assessed in dB (A).
A measured value at 125 Hz is for example perceived as 16.1 dB quieter than the same value at 1000 Hz.
The strength of the noise is dependent on the range at which it is measured and on the installation site. When measured a short distance from the source, the sound pressure level is higher, and at long distance it is lower. This reduction in sound level is referred to as dispersion damping.
For point sources, the following applies:

\[
L_{(r2)} = L_{(r1)} - 10 \log \left( \frac{r_2}{r_1} \right)^2
\]

- \( L(r1) \) = sound pressure level 1
- \( L(r2) \) = sound pressure level 2
- \( r_1 \) = distance 1
- \( r_2 \) = distance 2

Example:

\[
L_{(r0)} = 70 - 10 \log \left( \frac{20}{10} \right)^2 = 64 \text{ dB}
\]

\( L(r1) = 70 \) dB \hspace{1cm} \( r_1 = 10 \) m \hspace{1cm} \( r_2 = 20 \) m

As the distance doubles, the sound pressure level falls by 6 dB.

For installations comprising several gensets, the total noise level may be determined according to the laws of acoustics:

\[
L_\Sigma = 10 \log \left( \sum_{i=1}^{n} 10^{ \frac{L_i}{10} } \right)
\]

- \( L_\Sigma \) = total level
- \( L_i \) = individual level

Example:

\[
L_\Sigma = 10 \log \left( 10^{ \frac{70.5}{10} } + 10^{ \frac{71.5}{10} } + 10^{ \frac{72.5}{10} } + 10^{ \frac{75.5}{10} } + 10^{ \frac{77.0}{10} } \right) = 81.1 \text{ dB}
\]

- \( L_1 = 70.5 \) dB \hspace{1cm} \( L_2 = 71.5 \) dB \hspace{1cm} \( L_3 = 72.5 \) dB
- \( L_4 = 75.5 \) dB \hspace{1cm} \( L_5 = 77.0 \) dB

In simplified terms, when adding \( n \) equal levels \( L \), the following applies:

\[
L_\Sigma = L + 10 \log n
\]

When 2 equal sound levels are added, the level rises by 3 dB.

Where a genset is erected in a closed room, the noise is greater than in the open air as a result of the impeded dispersal of the noise. In small rooms with no acoustic material, the noise distribution is equal almost everywhere.
Large rooms with sound-absorbent walls offer acoustic benefits; tiles or similar construction materials should be avoided.

4.3.2 Possible means of mitigating noise

Normal wall thicknesses of 24 cm or 36 cm damp the noise coming from within by 40 to 50 dB. Nevertheless, silencer sections of 2 to 3 m in length must be provided for the air inlet and exhaust ducts, with approx. 40 dB noise reduction. Taking into account the volume of cooling air (see Chapter 5, Machine room ventilation), the air speed in the silencer section should not exceed approx. 8 m/s on the delivery side and approx. 6 m/s on the extraction side.

If acoustic materials such as sound insulating panels are installed in the genset room, the noise level can be reduced by approx. 3 dB, and indeed at greater expense even by approx. 10 dB. Particular care should be taken to control the exhaust noise. With suitable silencers, reductions in noise levels of up to approx. 60 dB can be achieved here.

Questions of sound insulation can only be solved on an individual basis, as they are highly dependent on local circumstances. By way of assistance, the manufacturer provides octave analyses of exhaust gas and engine noises. Sound insulation measures should be designed in collaboration with specialist firms.

Such measures might, for example, include:

- Exhaust silencing with the aid of reflection silencers, absorption silencers, active sound deadening
- Installing the genset so as to insulate against structure-borne noise
- Arrangement of absorption baffles for the genset room air inlet and outlet openings
- Housing the genset inside a sound-insulating enclosure
- Fitting the genset room with sound insulation and installing a floating floor (tasks for specialist firms)

No fiber materials (e.g. Heraklit) may be used to clad the interior of the room. Vibrations in the air cause particles to be released which then block the air filters and can even destroy the engine.

When sound-proofing the building, it is necessary to consider not only the walls but also the windows, doors and so on.

Technical sound-proofing considerations should also extend to additional sound sources such as auxiliary drives or dry coolers which are located outside of the engine room. Gas control lines, pre-pressure control lines or zero-pressure gas control lines, which are installed outside the engine room or outside a sound capsule, can also represent an additional noise source and must be considered in the technical sound design.
4.3.3 Noise data in genset data sheets

The sound values for airborne sound and exhaust gas sound are indicated as sound power levels in the genset data sheets. There are third octave spectra for the airborne noise and octave spectra for the exhaust noise. The specified levels in the third octave and octave bands are linear levels, meaning that no correction was made according to one of the assessment curves A, B, C and D. The overall noise levels are specified as total levels with an A assessment of the individual levels. In Table 4.2, the correction values are listed according to assessment A, B, C and D for the third octave bands.

Fig. 4.2 Noise data for a TCG 2020 V12
Tab. 4.2 Correction values for the third octave bands according to curves A, B, C and D

<table>
<thead>
<tr>
<th>Frequency Hz</th>
<th>A dB</th>
<th>B dB</th>
<th>C dB</th>
<th>D dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>-44.7</td>
<td>-20.4</td>
<td>-4.4</td>
<td>-18.5</td>
</tr>
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<td>31.5</td>
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<td>-11.6</td>
<td>-1.3</td>
<td>-12.5</td>
</tr>
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<td>-9.3</td>
<td>-0.8</td>
<td>-11.0</td>
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<td>-7.4</td>
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<td>-9.0</td>
</tr>
<tr>
<td>100</td>
<td>-19.1</td>
<td>-5.6</td>
<td>-0.3</td>
<td>-7.5</td>
</tr>
<tr>
<td>125</td>
<td>-16.1</td>
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<td>-2.5</td>
<td>-4.3</td>
<td>-4.4</td>
<td>+3.0</td>
</tr>
</tbody>
</table>
4.3.3.1 Conversion of sound power levels into sound pressure levels

The sound power is a variable that is independent of the distance and room and is suitable as a starting point for all technical sound calculations. It is not directly measurable and is established via specified measuring procedures.

The sound power level $L_w$ is the identifying sound technical variable for a sound source. In contrast to the sound pressure level $L_p$, the sound power level $L_w$ is fully independent of the sound field, i.e. independent of the size of the room and distance to the source. The emitted sound power of a noise source is determined here by measuring the sound pressure at several points of a closed measuring area $S$. The sound power of a source is calculated with the sound pressures measured on the defined enveloping surface. The ascertained sound power can be used to calculate the sound pressure levels at any distance from the sound source.

The following correlation applies to the sound pressure level at a distance of $x$ from the sound source:

$$L_p = L_w - 10 \cdot \log \left( \frac{S}{S_0} \right) \text{ [dB]}$$

The following results from specification with A-assessed levels:

$$L_{pA} = L_{WA} - 10 \cdot \log \left( \frac{S}{S_0} \right) \text{ [dB(A)]}$$

The following apply here:

- $L_p$: Sound pressure level, linear (without assessment)
- $L_{pA}$: Sound pressure level, assessment according to curve A
- $L_w$: Sound power level, linear (without assessment)
- $L_{WA}$: Sound power level, assessment according to curve A
- $S$: Measuring area at the distance $x$ to the sound source
- $S_0$: Reference surface, always 1 m²

4.3.3.2 Measuring surfaces for the genset

When determining the sound power level for the genset, a cuboid measuring surface at a distance of one meter from the genset is implied, see Fig. 4.3. The measuring surface is divided into a grid with a measuring point in the center of each individual grid surface. This procedure corresponds to DIN EN ISO 3476.
4.3.3.3 Measuring surfaces for the exhaust sound

With exhaust sound, a spherical measuring surface at a distance of one meter from the outer edge of the exhaust pipe is implied. The measuring surface is calculated with the equation:

\[ S = 4 \times \pi \times (D/2 + d)^2 \text{ [m}^2\text{]} \]

The following apply here:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>Measuring surface [m²]</td>
</tr>
<tr>
<td>D</td>
<td>Diameter of the exhaust pipe [m]</td>
</tr>
<tr>
<td>d</td>
<td>Measurement distance [1 m]</td>
</tr>
</tbody>
</table>

Fig. 4.3 Cuboid measuring surface for the genset

Fig. 4.4 Spherical measuring surface for the exhaust gas

1 Exhaust pipe
2 Measuring surface S
4.3.3.4 Examples of conversion sound power level – sound pressure level

Example 1:
How high is the sound pressure level for a genset TCG 2020 V12 at a distance of 1 meter and 10 meters?

The sound power level of the genset is specified in the data sheet as 121 dB(A).
The measuring surface S at a 1 meter distance is specified in the data sheet as 114 m².

The basic dimensions of a TCG 2020 V12 genset are:

<table>
<thead>
<tr>
<th>Length L</th>
<th>Width W</th>
<th>Height H</th>
</tr>
</thead>
<tbody>
<tr>
<td>[m] 5.7</td>
<td>[m] 2.1</td>
<td>[m] 2.5</td>
</tr>
</tbody>
</table>

An equivalent cuboid at a distance of 10 m has the dimensions:

<table>
<thead>
<tr>
<th>Length L</th>
<th>Width W</th>
<th>Height H</th>
</tr>
</thead>
<tbody>
<tr>
<td>[m] 5.7 + 2*10</td>
<td>[m] 2.1 + 2*10</td>
<td>[m] 2.5 + 10</td>
</tr>
</tbody>
</table>

This results in a measuring surface S of approx. 1763 m² at a distance of 10 meters. The following calculations are obtained with the equation mentioned above:

Sound pressure level at a 1 meter distance:

\[
L_{pA} = L_{WA} - 10 \times \log \left( \frac{S}{S_0} \right) \\
L_{pA} = 121 - 10 \times \log \left( \frac{114}{1} \right) \\
L_{pA} = 121 - 10 \times \log 114 = 121 - 10 \times 2.06 \\
L_{pA} = 100.4 \text{ dB(A)}
\]

Sound pressure level at a distance of 10 meters:

\[
L_{pA} = L_{WA} - 10 \times \log \left( \frac{S}{S_0} \right) \\
L_{pA} = 121 - 10 \times \log \left( \frac{1763}{1} \right) \\
L_{pA} = 121 - 10 \times \log 1763 = 121 - 10 \times 3.25 \\
L_{pA} = 88.6 \text{ dB(A)}
\]
Example 2:
How high is the exhaust sound pressure level for a genset TCG 2020 V12 at a distance of 1 meter and 10 meters from the exhaust outlet?
The sound power level for the exhaust gas is specified in the data sheet as 132 dB(A).
The reference surface S for a spherical surface with a radius of 1 m is specified in the data sheet as 15.5 m².
The surface S of a sphere with a radius of 10 meters is 1257 m²:
The following calculations are obtained with the equation mentioned above:

Sound pressure level at a distance of 1 meter from the pipe outer wall:

\[ L_{pA} = L_{WA} - 10 \cdot \log \left( \frac{S}{S_0} \right) \]
\[ L_{pA} = 132 - 10 \cdot \log \left( \frac{15.5}{1} \right) \]
\[ L_{pA} = 132 - 10 \cdot \log 15.5 = 132 - 10 \cdot 1.19 \]
\[ L_{pA} = 120.1 \text{ dB(A)} \]

Sound pressure level at a distance of 10 meters:

\[ L_{pA} = L_{WA} - 10 \cdot \log \left( \frac{S}{S_0} \right) \]
\[ L_{pA} = 132 - 10 \cdot \log \left( \frac{1257}{1} \right) \]
\[ L_{pA} = 132 - 10 \cdot \log 1257 = 132 - 10 \cdot 3.1 \]
\[ L_{pA} = 101 \text{ dB(A)} \]
Power plants layout

Chapter 5

Engine room ventilation

06-2017
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5. Engine room ventilation

An engine room is heated by convection and radiation from the engines, generators, heat recovery and piping systems installed therein. To avoid impermissibly high temperatures for the engines, components and switchgear, this heat must be dissipated with the aid of a ventilation system. Also, for systems operating in areas with extremely low ambient temperatures, it must be ensured that the minimum intake air temperatures specified in the genset data sheet are complied with. For this, it is recommended to utilize the radiation heat of the components to heat the engine room. In these cases, the engine room walls must be tight and good thermal insulation should be provided. In this respect, the design of the ventilation system is of particular importance; on the one hand, for the removal of the radiation heat in summer, and on the other hand, for the utilization of the radiation heat for engine room heating in winter.

General note: Intake air temperatures (and minimum temperatures) must comply with the values specified in the genset data sheets!

It must be ensured that the intake air temperature does not fall below the permissible starting temperature. See also Chapter 9.2, Requirements for the combustion air.

In the case of multi-engine systems, each genset should have its own adjustable ventilation system if possible.

The kind of ventilation systems feasible for engine rooms may be divided into three types (see Fig. 5.1):

5.1 Ventilation systems

5.1.1 Pressurized system (recommended)

Air at ambient temperature is drawn in from the outside by a fan, forced through the engine room and returned to the environment via exhaust openings. An overpressure prevails inside the engine room. The use of this system is especially recommended in environments with a high dust content (desert regions, etc.). The overpressure inside the engine room prevents dust from penetrating into the room through leaks in the walls of the building or through open doors or windows. The ventilation systems used must be fitted with appropriate filters to separate out the dust, e.g. inertia cyclone filters, dry type filters, etc. The degree of separation to be reached with the air supply filters used must correspond with the degree of separation of a class G3 filter. See also Chapter 5.4.4.
5.1.2 Extraction system (not recommended)

Outside air is sucked into the engine room via the air supply system (weather protection grille, filter, silencer and louvre); it then flows through the engine room before being extracted by a fan and returned to the environment. Negative pressure prevails inside the engine room.

The ventilation system is arranged on the suction side in such a way that the underpressure adjusting in the engine room is considerably below 1 mbar. Particularly in the case of gas engine systems that extract combustion air from the engine room, there may be complications on startup if the underpressure in the engine room is too high (see also Chapter 5.6, Notes on operating the ventilation system for gas engines).

Furthermore, the doors of the engine room, which serve as escape doors in emergencies and open outwards, are not easy to open if the underpressure is too high. The system works like a large vacuum cleaner and unfiltered secondary air enters as a result of leaks in the engine room doors and windows, which leads to the engine room becoming contaminated more and more over time. The degree of separation to be reached with the air supply filters used must correspond with the degree of separation of a class G3 filter. See also Chapter 5.3.4.

5.1.3 Combined system (recommended)

The air to ventilate the engine room is blown into the engine room by a supply air fan and extracted by another fan on the exhaust side. By suitably tuning the supply and exhaust systems, the air pressure in the engine room is approximately equal to the external ambient pressure.

This system must definitely be used for systems which exhibit significant pressure losses at both the supply side and the exhaust side. This is particularly the case where the air for the engine room ventilation must be drawn in and discharged again over great distances and the pressure loss is compounded by components such as weather protection grilles, sound-proofing baffles, louvres and filters.

5.1.4 Ventilation by use of frequency-controlled fans

When operating gas engines, the intake air temperature must be kept in a relatively narrow range. The minimum air temperature indicated in the data sheet must not be fallen below, as otherwise the compressor of the exhaust turbocharger will pump. Engines with an exhaust wastegate permit a further range of the intake air temperature.

In the case of a ventilator with a fixed speed that is designed for summer conditions, the required minimum intake temperatures for the engine may not always be maintained in winter. By adapting the ventilation volumetric flow rate and the use of radiant heat from the engine and generator, the use of frequency controlled ventilators allows the intake air temperature to be kept in the permissible range even at varying ambient temperatures using a control. It is possible to control the intake air temperature by adapting the ventilation volumetric flow up to ambient air temperatures of approx. 0 °C; a circulation system is required for lower ambient temperatures.
5.1.5 Circulating air temperature control

To avoid unacceptably low temperatures in the engine room, the room temperature can be controlled by mixing exhaust air in with the supply air. For all systems, the air flow must be designed in such a way as to ensure that the air flows through the entire engine room; there must be no short-circuit currents from the supply opening to the exhaust opening, thus ensuring that there is adequate air circulation around the heat-producing components. If necessary, air ducts must be installed which provide an air flow specifically targeted towards the individual components in the engine room.

In order to minimize the radiated heat occurring in the engine room and thus the volume of air required, silencers and exhaust pipes inside the engine room must be insulated. It is generally necessary to insulate exhaust systems inside buildings.

In many cases, the combustion air for the engines is drawn from the engine room. This additional volume of air must be taken into consideration when designing the supply air fans. Dependent on the design of the system, the engine air filters could be located in areas in which the air has already undergone considerable heating. In such cases, cold air must be conducted to the air filters via separate ventilation ducts.
Fig. 5.1a Ventilation systems

Pressurized system

Extraction system (not recommended)

1  Supply air
2  Exhaust air
3  Weather protection grille
4  Filter
5  Sound-proofing baffle
6  Supply air fan
7  Supply air louvre
8  Exhaust air louvre
9  Exhaust air fan
Fig. 5.1b Ventilation systems
System with circulating air temperature control (recommended)

Combined system (recommended)

1 Supply air
2 Exhaust air
3 Weather protection grille
4 Filter
5 Sound-proofing baffle
6 Supply air fan
7 Supply air louvre
8 Exhaust air louvre
9 Exhaust air fan
10 Circulating air duct
11 Circulating air louvre
5.2 Determining the demand for air

The required volume of air to be determined in order to design the ventilation system is composed of the following individual requirements:

5.2.1 Combustion air requirement

If the combustion air is drawn from inside the engine room, it must be included in the layout of the ventilation air system for the engine room. The combustion air temperature is one of the factors which influence the location-dependent output achievable by the engine. It must therefore be guaranteed that the air temperature in the area of the intake neither exceeds nor falls short of the value established to determine the location-dependent output.

5.2.2 Cooling air requirement for the engine and components

The radiation heat from the engine, the generator and other components in the engine room which radiate heat, such as pumps, separators, heat exchangers, boilers, etc., must be discharged via the engine room ventilation system.

Components, which radiate heat and operate only intermittently, such as compressors, are likely to be neglected in most cases when determining the demand for cooling air.

5.3 Determining the radiation heat

To determine the demand for air, the heat radiated from the engine and generator must be determined first.

5.3.1 Radiation from the engine

The heat levels (QM) radiated from the engine are always stated in the current data sheets.

5.3.2 Radiation from the generator

The heat levels radiated from the generator (QG) are always stated in the current data sheets.

5.3.3 Radiation from auxiliaries

The heat radiated from pipes, especially exhaust pipes, exhaust silencers, radiators and pump units can be determined only with considerable effort. Experience indicates that this radiated heat equates to approx. 10 % of the heat radiated from the engine.

\[
Q_H = 0.1 \times Q_M
\]

\[Q_H\] [kW] heat radiated from auxiliaries
\[Q_M\] [kW] heat radiated from the engine
5.3.4 Radiation from the heat recovery unit

If components are installed in the genset room to utilize the heat energy, experience indicates that the heat radiated from the cooling water and exhaust heat exchangers will be approx. 1.5 % of the respective available heat as per the data sheet.

\[
Q_W = 0.015 \times (Q_{KW} + Q_{Abg})
\]

\(Q_{WN}\) [kW] heat radiated from the heat recovery unit
\(Q_{KW}\) [kW] engine cooling water heat
\(Q_{Abg}\) [kW] available engine exhaust heat

5.3.5 Total radiated heat

The total radiated heat \(Q_S\) is the sum of the above-mentioned proportions:

\[
Q_S = Q_M + Q_G + Q_H + Q_W
\]

Depending on ambient conditions, some of the radiated heat is dissipated via the engine room walls. This proportion can be determined only with great difficulty owing to variable circumstances such as the ambient temperature or the design of the engine room walls, and is therefore not taken into account.

5.3.6 Required ventilation air (excluding the combustion air for the engine)

Finally, the required air is a function of the total radiated heat, the permissible rise in air temperature in the engine room and the specific heat capacity of the air:

\[
m_{Lerf} = \frac{Q_S \times 3600}{\Delta T \times c_p}
\]

\(m_{Lerf}\) [kg/h] required air mass flow for cooling
\(Q_S\) [kW] total radiated heat
\(\Delta T\) [K] permissible rise in temperature
\(c_p\) [kJ/kgK] specific heat capacity of the air (1.005 kJ/kgK)

The above equation calculates the required air mass flow. To determine the required volume flow, the density of the air must be taken into account. The density depends on the air temperature, the air pressure and the relative humidity. The required volume flow is:
The required air mass flow \( m_{\text{Lerf}} \) and required air volume flow \( V_{\text{Lerf}} \) are given by:

\[
V_{\text{Lerf}} = \frac{m_{\text{Lerf}}}{\rho_L}
\]

- \( m_{\text{Lerf}} \) [kg/h] required air mass flow
- \( V_{\text{Lerf}} \) [m³/h] required air volume flow
- \( \rho_L \) [kg/m³] air density (e.g. 1.172 kg/m³ at 1002 mbar and 25 °C)

The air pressure reduces as the geodetic altitude increases. The following table indicates pressures and densities depending on temperature and the geodetic altitude.

The specified values apply to dry air. With moist air, the density falls as relative humidity rises. At a relative humidity of 60 %, the drop in density can be up to 10 %.

**Table 5.2**

<table>
<thead>
<tr>
<th>Geodetic height in m</th>
<th>Temperature 25 °C</th>
<th>Geodetic height in m</th>
<th>Temperature 25 °C</th>
<th>Geodetic height in m</th>
<th>Temperature 25 °C</th>
</tr>
</thead>
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<tr>
<td></td>
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<td>mbar</td>
<td>kg/m³</td>
<td>mbar</td>
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<td>700</td>
<td>940</td>
<td>1.099</td>
</tr>
<tr>
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<td>1002</td>
<td>1.172</td>
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<td>930</td>
<td>1.087</td>
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<td>950</td>
<td>1.110</td>
<td>1600</td>
<td>853</td>
<td>0.997</td>
</tr>
</tbody>
</table>

The densities can be converted for other temperatures by applying the following equation:
\[ \rho(t) = \rho_{(25^\circ \text{C})} \frac{(273+25)}{(273+t)} \]

- \( \rho_{(25^\circ \text{C})} \) [kg/m³]: air density at 25 °C
- \( \rho(t) \) [kg/m³]: air density at temperature \( t \)
- \( t \) [°C]: air temperature

In the case of systems which extract air from the engine room, on the supply side, the volume of air for combustion in the engine must also be taken into account. Chapter 9.2 contains guide values for the specific combustion air volume required for the individual engine models.

### 5.4 Ventilation system components

The principal components of an engine room ventilation system are the weather protection grilles, silencers, louvres, filters, air ducts and fans.

#### 5.4.1 Weather protection grille

Weather protection grilles are installed on the outside wall of the engine room on both the supply and the exhaust sides. They prevent rain and snow from entering into the ventilation system. A bird screen must also be integrated into the weather protection grille to stop small animals, etc., from entering the system.

#### 5.4.2 Sound-proofing baffles

Especially when systems are installed in residential areas or areas with restricted noise levels, significant effort may be required in terms of measures to sound-proof the ventilation system. In such cases, sound-proofing baffles must be fitted at the air supply and exhaust air sides. The principal data required for their design are the air flow to be supported through the screen, the required level of sound-proofing and the available duct opening. Thereafter, the depth of the baffles, their thickness and distance to each other are determined.

The sound-proofing baffles must be designed by specialized companies, a task which calls for an appropriate degree of care, as subsequent improvements are very costly if the required figures are not achieved.

#### 5.4.3 Louvres

Louvres are used to block the ventilation system link between the engine room and the external environment when the system is at a standstill, especially in winter to prevent excessive cooling of the room. The louvres are activated by electric drives which are controlled from the switchgear. In large systems, cool air can be admitted to certain areas of the system by actively controlling the louvres. In winter, the engine room temperature can be regulated by controlling the louvres.
5.4.4 Filter

Generally, filters should be installed in the ventilation system. This particularly applies to systems located on industrial sites where the ambient air is heavily contaminated, e.g. landfills, coal mines, cement works, metallurgical plants, etc. It is also applicable for systems located in regions where sand storms may occur. Here the appropriate filter type must be selected according to the degree of the contamination. Heavy particles are easily separated via inertia filters, whilst for example, where lightweight fibers occur, conventional fibrous filters must be fitted, which, in view of the relatively large quantities of air, can achieve considerable dimensions.

Filters as per DIN EN 779, Filter Class G3, are suitable. In case of specific requirements, a correspondingly higher filter class needs to be chosen. An effective filter monitoring is necessary.

5.4.5 Ventilators

The ventilators are designed mostly as axial fans - rarely as radial fans - and must be of a suitable size depending on the required quantity of air and pressure difference. To control the engine room temperature, the volume of air being blown can be adjusted by using variable-speed fans or by switching individual fans on and off.

**Important**: When using individual fans - particularly axial types - it must be considered that standing fans can be driven in reverse by a difference in pressure. With large fans, this can lead to problems.

When determining the size of the fans, the pressure reserve must be correctly selected with respect to the components installed in the ventilation system, such as weather protection grilles, sound-proofing baffles, louvres, etc., in order to ensure that the designed quantity of air is actually achieved.

5.4.6 Air ducts

Depending on the design of the system or the location of the engine room inside a larger building, e.g. in the basement in the case of emergency power systems, the air to ventilate the engine room may have to be brought in over longer distances. For this purpose, air ducts are employed. The pressure losses in these ducts must be considered when designing the fans. To avoid condensation, outside air ducts should be insulated.

5.5 Planning notes

Having determined the required quantities of air, the openings and ducts must be so designed as to ensure compliance with the following air speeds.


Table 5.3

<table>
<thead>
<tr>
<th>Component</th>
<th>Air speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply / exhaust opening</td>
<td>1.5 - 2.5 / 2.5 - 4</td>
</tr>
<tr>
<td>Ventilation duct</td>
<td>10 - 20</td>
</tr>
<tr>
<td>Free flow in the engine room</td>
<td>0.3</td>
</tr>
<tr>
<td>Silencer section</td>
<td>6 - 8</td>
</tr>
</tbody>
</table>

Additional restrictions owing to flow noise must be taken into account.

5.5.1 Changes of air

The number of air changes also may be taken as a characteristic figure for a ventilation system. It represents the number of air changes per hour, i.e. saying how often the complete volume of air in the engine room is exchanged.

From experience, the number of air changes should not exceed 100 for big systems in buildings. With extremely small engine rooms (e.g. containers) or at high ambient temperatures, the number of air changes may rise up to 500 per hour.

5.6 Notes on operating ventilation systems for gas engines

The operation of the ventilation system may affect the pressure conditions at the combustion air intake of the engine in such a way as to cause engine starting problems, or even making starting impossible. In such cases, before starting the engine, only the supply and exhaust louvres must be opened. During start or synchronization, the fans must operate without pressure peaks in the engine room, i.e. during the genset starting phase, the fans must be operated with constant speed.

5.6.1 Position of supply and exhaust openings

Supply openings must be positioned in such a way that the air drawn in is as clean and cool as possible. The position for the outlet of exhaust air must be selected so that the function of other system components such as cooling systems is not impaired by the warm exhaust air flow.
Power plants layout

Chapter 6

Engine cooling systems

06-2017
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6. Engine cooling systems

The cooling systems employed have water as a cooling medium and from an engine perspective must be closed systems.

The genset engines essentially feature two types of cooling: single-circuit and dual-circuit.

The layout must follow the illustrations included hereinafter. Deviations require approval in writing.

6.1 Single-circuit cooling

The coolant of gas engines with a single-circuit passes through the lube oil cooler, the intercoolers and the engine, i.e. the total heat is discharged in one single circuit.

6.2 Dual-circuit cooling

Along with an engine water cooling circuit, engines with a dual-circuit also have a low-temperature mixture/charge air cooling circuit. As the temperature level in the mixture cooling circuit is comparably low, the heat from that circuit is normally discharged to the environment via fan coolers or cooling towers with a separate circuit.

6.2.1 Gas engines

All gas engines of the series TCG 2016 C, TCG 3016, TCG 2020 and TCG 2032 are equipped with a two-stage intercooler on the engine. The high temperature stage is integrated into the engine cooling circuit and the heat from low temperature stage is discharged in the external mixture cooling circuit.

For the TCG 2032 engines, since the lube oil cooler is not mounted on the engine, depending on the layout of the system as a whole, it can be installed on the water side in the engine cooling circuit, in the low temperature mixture cooling circuit or in the heating water circuit. Please see also Chapter 8.2.

6.2.1.1 Example for the layout of cooling systems with gas engines

The heat absorbed by the cooling water is transferred via a heat exchanger to be provided by the client for use in a heating water circuit or other technical process. If there is no means of heat recovery at hand, it must be discharged into the atmosphere via a radiator or cooling tower. It is not permitted to run the cooling tower water straight through the engine! A decoupling heat exchanger or closed cooling tower must be provided.

The inlet temperature of the cooling water is generally controlled, whereby dependent on the design of the system, the temperature regulator may be installed directly in the engine circuit or in the heating circuit. Electric pumps are always used as cooling water pumps, the fine adjustment of the cooling water flow being achieved via an adjustable throttle. The expanding volume is accommodated in a diaphragm expansion
vessel, the level in the cooling water circuit being monitored by the so-called monitoring group. Integrated in this group are a safety valve, venting and blow-off valves and the low-water level safety device. As with the engine circuit, the mixture cooling circuit is equipped with an electrical circulating pump, diaphragm expansion vessel, monitoring group and temperature regulator. With multi engine plants, it is not permitted to connect the engine cooling circuits together, because the definitive regulating of each HT-inlet-temperature can not be guaranteed.

Fig. 6.1 shows a cooling system without heat utilization.
Fig. 6.2 shows a cooling system with heat utilization.
Fig. 6.1 P&I flowchart for system without heat utilization

A  Combustion gas  ASD  Exhaust silencer
B  Condensate  DV  Throttle valve
MRA10  Genset  EVH  Electric pre-heating
MRN10  Gas control line  FU  Frequency converter
MRE50  Engine cooling system  KAT  Catalyst
MRE60  Mixture cooling system  TK  Table cooler
Fig. 6.2 P&I flowchart for system with heat utilization

A  Combustion gas  ASD  Exhaust silencer
B  Condensate  AWT  Exhaust heat exchanger
MRA10  Genset  BK  Bypass flap
MRA40  Exhaust system  DV  Throttle valve
MRE20  Heat utilization  EVH  Electric pre-heating
MRE60  Mixture cooling system  FU  Frequency converter
MRE70  Emergency cooling circuit  KAT  Catalyst
MRN10  Gas control line  KWT  Cooling water heat exchanger
             NK  Emergency cooler
             TK  Table cooler
6.3 Reference values for the layout of cooling systems

6.3.1 Pressures

All pressures for fluids are generally indicated in bar overpressure. All heat exchangers, pumps and table coolers should be designed as standard for 10 bar, the lube oil heat exchanger of the TCG 2032 for 16 bar.

6.3.1.1 Minimum pressure

The minimum permitted dynamic pressure at the engine outlet is 1.5 bar. All gas engines have monitoring of the pressure at the cooling water outlet in the engine cooling circuit. If the value falls below 1.5 bar a warning is output, if the value falls below 1.0 bar the engine is switched off. The diaphragm expansion vessels should be dimensioned in such a way that a minimum pressure of 1.5 bar is retained when the plant is stopped.

6.3.1.2 Maximum pressure

The maximum permissible pressure at the engine outlet is 2.5 bar. The safety valve mounted close to the engine outlet opens at approx. 3 bar.

6.3.2 Pump location

If there are high pressure losses as a result of external resistance in the engine circuit (heat exchangers, regulating valves, etc.), the pump must be installed on the outlet side of the engine, otherwise the maximum permitted pressure on the outlet side or the minimum pressure is out of limit.

6.3.3 Max. permissible temperature gradient

If the inlet temperature of the engine, mixture cooling and emergency cooling circuit as well as the inlet temperature of the heating circuit are regulated by the customer, the max. permissible temperature modification speed of 1 K/min needs to be maintained.

In order to maintain a stable behavior of the temperature control for the engine cooling circuits, it is necessary to minimize the influence of disturbing parameters from external systems. It is essential that all coolers and pumps have an adequate reserve in capacity and flow rate.

6.4 Cooling water system components

6.4.1 Cooling water heat exchanger

Reserve capacity and surface area reserve according to Table 6.3 must be observed. The specified engine inlet and outlet temperatures must be observed (see engine data sheet).
In order to keep the heat exchangers in a good condition from an economic point of view, the logarithmic temperature difference should not be lower than 4 K. The temperature difference between inlet and outlet (primary / secondary circuit) should be greater than 2 K (see also Fig. 6.3).

In the case of liquid coolants on the secondary side, plate heat exchangers or pipe radiators are used. Plate heat exchangers are highly compact in construction and easy to clean. Their performance can, within certain limits, be varied at a later date by altering the number of plates.

**Fig. 6.3 Logarithmic temperature difference**

A Operating media 1  
B Operating media 2  
\( \ln \) Natural logarithm  
\( \Delta \theta \) Logarithmic temperature difference

**Example**

A cooling water heat exchanger in the heating circuit has the following design data:

| Engine side: | Inlet temperature \( \vartheta'_1 \): 90 °C | Outlet temperature \( \vartheta''_1 \): 84 °C |
| Heating circuit side: | Inlet temperature \( \vartheta'_2 \): 70 °C | Outlet temperature \( \vartheta''_2 \): 85 °C |

This yields:

- \( \Delta \theta_A \): \((90 \, ^\circ\text{C}-85 \, ^\circ\text{C})\) = 5 K
- \( \Delta \theta_E \): \((84 \, ^\circ\text{C}-70 \, ^\circ\text{C})\) = 14 K
- \( \Delta \theta_A-\Delta \theta_E \): (5-14) K = -9 K
- \( \ln(\Delta \theta_A/\Delta \theta_E) \): \(\ln(5/14)\) = -1.0296
- \( \Delta \theta \): (-9 K/-1.0296) = 8.74 K

This plate heat exchanger therefore complies with the minimum requirements \( \Delta \theta \geq 4 \, K, \Delta \theta_A \) and \( \Delta \theta_E \geq 2 \, K \).
6.4.1.1 Implementation of cooling water heat exchangers with emergency cooling by raw water

For emergency cooling systems with raw water cooling via heat exchanger, the temperature control for the emergency cooler outlet temperature should be arranged in the primary circuit (see Fig. 6.5a). With this design, hot water flow over the emergency cooler will only occur when emergency cooling is requested. The water outlet temperature on the secondary (raw water) side of the emergency cooling heat exchanger must be kept below 45 °C in order to prevent sedimentation of lime. In any case, the temperature control should not be as per Fig. 6.5b. In this case, there is always hot water flow through the emergency cooling plate heat exchanger. In the case of no or low water flow rate on the secondary side, the raw water temperature in the heat exchanger will rise and reach the temperature level of the hot water side. The plate heat exchanger will become calcified over time. The temperature gradient on the raw water side must not exceed +/- 1 K/min. For the actuators of the temperature control valves, the I/O-Controller of the TEM system has digital outputs for +/- (24 V signal) for opening/closing the valve. In order to achieve a reasonable control behavior, the running time of the valve from limit position open to limit position close and vice versa should be in the range of 1 minute.

Fig. 6.4a Correct layout

![Correct layout diagram]

Fig. 6.4b Incorrect layout

![Incorrect layout diagram]

A  Engine cooling circuit
B  Primary side (engine / heating circuit)
C  Secondary side
NK  Emergency cooler
6.4.2 Exhaust heat exchanger

Reserve capacity and surface area reserve according to Table 6.3 must be observed. For the setting of the exhaust outlet temperature from the exhaust heat exchanger, the amount of H₂S and sulfur in the combustion gas must be considered. This is to avoid acid condensate in the exhaust which will damage the exhaust heat exchanger.

Recommended exhaust gas cooling temperatures:
- Natural gas: ≥ 120 °C
- Sewage gas: ≥ 150 °C
- Landfill gas and NAWARO gas: ≥ 180 °C

The minimum volume flow specified by the manufacturer must be complied with in order to guarantee sufficient cooling of the exhaust heat exchanger. After stopping the genset, it is necessary to keep the cooling water pump running for a while in order to discharge the accumulated heat from the exhaust heat exchanger. This function is part of the TEM system.

6.4.3 Cooling systems

Each cooling system must be capable of discharging the generated heat even at maximum ambient temperatures.

Where air is used as the secondary side coolant, fan coolers and cooling towers are employed. Up to a certain size, fan coolers can be implemented as front coolers (vertically arranged cooling network); larger systems take the form of table coolers. In the case of front cooling systems, the fans push the air through the cooling network; with table cooling systems, the air is pulled through the cooling network. The occasionally high noise level of the fans must be taken into account when installing systems in residential areas. Either slow-moving fans can be used here, or special sound-proofing measures will be needed.

6.4.3.1 Table cooler

Reserve capacity and surface area reserve according to Table 6.3 must be observed. Where there is a risk of contamination resulting from the environment (e.g. leaves, pollen, sand, carbon dust etc.), an appropriate fin spacing must be selected. An enlarged space between the fins prevents the cooler from becoming clogged too fast. Otherwise the heat cannot be dissipated anymore due to the worsening of the heat transfer. In the case of air coolers, because of the risk of freezing, anti-freeze must be added to the cooling water. When installing the table cooler, it must be ensured that there is sufficient space beneath to allow a proper air flow. Where several coolers are installed, there must be an adequate spacing between them to prevent a short-circuit.
If the table coolers are arranged at a level higher than 15 m above the engine level, it is necessary to install a heat exchanger in order to keep the pressure level in the engine in the permissible range mentioned in section 6.3.1.2.

6.4.3.1.1 Table cooler control

The power of table coolers is influenced both by the ambient temperature and the number of running fans or the fans’ speed. When controlling the table cooler power via the number of operating fans, we talk about step control; for control via the speed of the fans via FU or EC control. The FU/EC control offers the advantage of continuous adaptation of the cooler power to thermal power which should be discharged. For the different engine types, the fan control for the table coolers in the different cooling circuits should be as per Table 6.2. For the discharge of the heat in the mixture cooling circuit, and/or engine/emergency cooling circuit, the following assignment must be ensured for the gas engines.

Table 6.2 Table cooler control

<table>
<thead>
<tr>
<th>Engine Type</th>
<th>Cooler GK</th>
<th>Cooler MK</th>
<th>Cooler NK</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCG 2032</td>
<td>FU/EC controlled</td>
<td>FU/EC controlled</td>
<td>FU/EC controlled</td>
</tr>
<tr>
<td>TCG 2020</td>
<td>FU/EC controlled</td>
<td>FU/EC controlled</td>
<td>FU/EC controlled</td>
</tr>
<tr>
<td>TCG 2016 C</td>
<td>FU/EC controlled</td>
<td>≥ 6 steps</td>
<td>≥ 6 steps</td>
</tr>
<tr>
<td>TCG 3016 C</td>
<td>FU/EC controlled</td>
<td>≥ 6 steps</td>
<td>≥ 6 steps</td>
</tr>
</tbody>
</table>

EC = Electronically commutated; FU = frequency converter; GK = mixture cooling circuit; MK = engine cooling circuit; NK = emergency cooling circuit;

In summary, the heat in the mixture cooling circuit must be discharged via frequency controlled table coolers for all gas engine types. For the engine types TCG 2016 C and TCG 3016, the engine cooling circuit (MK) and the emergency cooling circuit (NK) may be equipped with at least a 6-step cooler (6 fans). Fewer than 6 steps is not permissible. Alternatively, the FU controlled variant is recommended. With extremely low ambient temperatures, i.e. regularly low temperatures below -15 °C, all cooling circuits must be controlled via a frequency converter. By this requirement, the boundary conditions for proper operation of the gas engines can be kept for a wide range of altering ambient conditions.

6.4.3.1.2 Sandwich table cooler (not recommended)

A special design of table cooler is a sandwich table cooler. With this table cooler type, there are two cooling stages arranged one upon the other and the air supply is provided by common fans. The first stage is the LT-stage (LT=Low Temperature), the second stage the HT-stage (HT=High Temperature). Normally, the heat
from the mixture cooling circuit is discharged in the LT-stage and the heat from the engine in the HT-stage. This cooler type is applied for plants with power generation, because, only for this application, the load on both stages is uniform for the whole power range of the engine. For CHP plants, normally the HT-stage of a sandwich table cooler is used for emergency cooling purposes. With heat utilization (no or minimal heat rejection via emergency cooler), the speed of the common fans is defined by the heat to be discharged from the mixture cooling circuit in the LT circuit. For this mode of operation, the emergency cooler (HT-stage of the sandwich table cooler) might be ineffectively oversized and, as a consequence, the temperature control for the system might become unstable. Therefore the use of sandwich table coolers is not agreed for CHP systems.

6.4.3.1.3 Installation and layout of table coolers

Reserve capacity and surface area reserve according to Table 6.3 must be observed. Where there is a risk of contamination resulting from the environment (e.g. leaves, pollen, sand, carbon dust etc.), an appropriate fin spacing must be selected. An enlarged space between the fins prevents the cooler from becoming clogged too fast. Otherwise the heat cannot be dissipated anymore due to the worsening of the heat transfer. In the case of air coolers, because of the risk of freezing, anti-freeze must be added to the cooling water. When installing the table cooler, it must be ensured that the installation height above the ground is sufficient to allow a proper air flow. The free inflow area for the air supply must correspond at least to the floor space of the table cooler. Where several coolers are installed, the short-circuiting of air flows must be prevented. Table coolers should therefore be installed either flush next to each other or with sufficient space between them. When doing so, erect the table coolers so that the required inflow area for the air supply is ensured at the free sides.
Fig. 6.5a Installation of table coolers

1  Floor space of an individual table cooler
2  Supply flow areas of cooling air A1 and A2 (not visible) for this table cooler

Fig. 6.5b Installation of table coolers

1  Floor space of all table coolers
2  Supply flow areas of cooling air A1, A2 and A3 (not visible) and A4
6.4.3.2 Cooling towers

Cooling towers exploit the evaporation cooling effect and are used in both closed and open forms. With an open cooling tower, part of the circulating cooling water (approx. 3 %) evaporates. The volume of water lost to evaporation must always be replenished. In addition, a blow-down device is to be provided in order to avoid an undue increase in concentration of dissolved salts in the supplementation water in the cooling tower.

Since all corrosion- and/or frost-protected engine cooling circuits require the use of treated water, these cooling circuits may only be connected to an open cooling tower via a decoupling heat exchanger.

With open cooling towers, it is necessary to clean the decoupling heat exchanger more often because the open water circuit favors the formation of algae polluting the heat exchanger. The thicker the layer of algae in the heat exchanger, the worse the heat transfer. No more heat is dissipated in the circuits to be cooled.

In the case of closed cooling towers, the cooling water tubes are sprayed with water, causing the water to evaporate and thereby cooling down the operating media in the tube. Since there is no loss of water in the cooling circuit itself, closed cooling towers can be linked directly to the engine cooling circuit. The most important design parameters for economical cooling tower operation are the air temperature and, above all, the humidity.

6.4.4 Layout of components - Reserves

In the case of the layout of components for the cooling water system, the reserves must be observed. The amounts of heat given in the data sheets are nominal values, which do not consider tolerance for possible increased fuel consumption. In the following table, the reserves for capacity and area are specified and have to be considered for the design.

Table 6.3 Reserves for capacity and area

<table>
<thead>
<tr>
<th>Component</th>
<th>Reserve capacity [%]</th>
<th>Surface area reserve [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat exchanger water/water</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Heat exchanger water/oil</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Ventilator cooler</td>
<td>15</td>
<td>5</td>
</tr>
</tbody>
</table>
| Exhaust heat exchanger    | 7                    | 10 for natural gas
                          |                       | 0 for biogas, sewage gas and
                          |                       | landfill gas etc.|

Example:

In a data sheet for a TCG 2020 V20, a cooling water heat of 1000 kW is specified.

The cooling water heat exchanger must be designed for a capacity of 1150 kW with an area reserve of 5 %.
6.4.5 Chillers

Chillers should not be directly integrated into the engine cooling circuit. In case of leakages, the engine cooling water might be contaminated by e.g. Li Br. This is prevented by the coupling heat exchanger in the engine cooling circuit.

There are cases in which the required water-temperature level of the chiller can only be achieved via a direct integration in the cooling water circuit of the engine. In this case, one has to comply with the following conditions:

- The requirements with respect to the quality of the cooling water of the engine, corrosion protection or freezing protection have to be met.
- The cooling water additives which are approved by the manufacturer of the engines need to be approved for the chiller as well.
- In case of leakages in the heat exchanger of the chiller, both the cooling system and the engine can be damaged. The manufacturer of the engine accepts no liability for those damages.

6.4.6 Cooling water pumps

A fixed volume flow must be observed over the entire load range in the engine cooling water circuit and in the mixture circuit (MK and GK) for all series. Therefore cooling water pumps driven by electric motors with fixed speeds corresponding to the network frequency are generally used. If pumps with frequency-controllable electric motors are used, these must be set to a fixed speed corresponding to the plant operating point.

In the case of systems with heat recovery from the cooling water, to achieve the maximum efficiency and component service life, the engine inlet temperature and outlet temperature must be exactly maintained. In order to more accurately and individually coordinate the required pump capacity and the lift needed for each installation, electric pumps selected with regard to the operating point are used for these systems. In the design of heat exchangers and table coolers, the specified reserve capacities must be considered, see sections 6.4.1, 6.4.2 and 6.4.3.1. This increased heat output must be taken into consideration with increased volume flow, while maintaining the design temperature. When determining the size of pump, the increased volume flow according to the capacity reserve and the associated higher pressure losses must be taken into account. In order to attain the desired design temperature spread, the speed must be fixed for the design point in the case of pumps with frequency-controllable drive motors. In the case of pumps with non-controllable drive motors, the cooling water volume is set precisely via a throttle valve.

Electric pumps with fixed speeds are also generally used in heating circuits with a return temperature increase via a three-way valve. Special requirements in the heating circuit, e.g. maintaining a constant flow temperature in the part-load range of the genset, are occasionally shown just by a variable volume flow in the heating circuit. In these cases, pumps with frequency-controlled electric motors are used. If exhaust heat exchangers are installed in these heating circuits, it must be ensured that the volume flow at no point during
operation falls below the minimum stated for the exhaust heat exchanger. Otherwise the exhaust heat exchanger might overheat or become damaged.

Block pumps are generally used in inline design with standard engines. The water chamber is sealed by an uncooled floating seal. The pumps must not be operated when dry, since the floating seal is damaged in the case of dry running. Attention must also be paid when filling the cooling water systems that they are filled with preconditioned coolant. Pure anti-freeze can also damage the floating seal.

6.4.7 Diaphragm expansion vessels

To compensate the expansion in volume as the cooling water heats up, diaphragm expansion vessels are provided in the cooling system. The expansion in volume as the cooling water heats up is compensated for by compressing a gas bubble. The resulting static increase in pressure in the system is dependent on the size of the expansion vessel selected. Expansion vessels must be connected on the inlet side of the pump. Where a diaphragm expansion vessel is used, the cooling water circuit must be protected against overpressure by a safety valve. In the engine and mixture cooling circuit, safety valves with a response pressure of 3.0 bar are used. The installation site should be as close as possible to the engine cooling water outlet.

When designing the expansion vessel, the static pressure, the flow pressure loss between the safety valve and the expansion vessel and the water supply must be considered. The water supply in the engine and mixture cooling circuit must equate to 10-15 % of the cooling water content, subject to a minimum of 20 liters.

6.4.8 Temperature regulators

The temperature regulators are electronic regulators with electric actuators.

Electronic temperature regulators can control the set temperature at a constant setpoint value; the regulating variable may be located in an external circuit. Precise temperature regulation is needed, especially in the case of systems where heat is recovered and, at the same time, high overall efficiency is called for.

The nominal diameters of the temperature regulation valves must be determined so as to ensure that, at the respective nominal rate of flow, the pressure loss via the valve lies within a range of 0.2-0.5 bar in straight flow (bypass closed).

6.4.9 Cooling water monitoring group

There are three functions integrated into the cooling water monitoring group: security against overpressure, venting the cooling circuit and cooling water level monitoring. The cooling water monitoring group must be installed at the highest point in the cooling water system, if possible directly after the engine. For engines of the series TCG 2016 C and TCG 3016, ventilation lines must be fed to the monitoring group.

In addition, it is also necessary to monitor the flow of cooling water through the engine via differential pressure.
6.4.10 Cooling water preheating

Gas engine gensets must, as a matter of principle, be equipped with a cooling water preheating to ensure reliable engine starting. For the engine series TCG 2032, complete pre-heating gensets with a pump, heat exchanger with heating elements and electrical control are used as a pre-heating system for the engine water and oil. For the series TCG 2016 C, TCG 3016 and TCG 2020, a pre-heating system has been developed which is installed in the cooling water line ahead of the engine. The electrically driven cooling water pump is used for circulation. It is controlled via the TEM system.

6.4.11 Cooling water pre-heating in gensets in flex operation

As already mentioned in Chapter 2.4, adjustments to the cooling water pre-heating and pre-lubrication systems are required in order to guarantee the readiness of the gas engine gensets when providing control energy. Quickly starting up and subsequently transferring loads require that the gensets and/or the complete engine cooling system are constantly pre-heated to temperatures above 60 °C. If hot water is available from one external heating system, it can be used to keep the gensets warm. In CHP gensets the cooling water heat exchanger is used as a heat exchanger, while the water circulation is taken over by high-efficiency wet rotor pumps. In this case, the conventional electrical pre-heating system with a connection for the engine cooling water pump only has a back-up function. In flow modules an additional small heat exchanger is integrated into the system for transferring heat. This minimizes the consumption of electrical energy for pre-heating during the phases when the gas engine gensets are at a standstill. The principal layout of a “Flex pre-heating” system is shown in Fig. 6.6 for the CHP genset and Fig. 6.7 for the flow module. Control of the pre-heating is implemented in the auxiliary drive cabinet.
Fig. 6.6 Flex pre-heating of CHP genset

1 Heating circuit pump
2 Engine circuit pump
3 Electric pre-heating
4 Engine circuit circulation pump
5 Heating circuit circulation pump
6 Solenoid valve
TK Table cooler
KWT Cooling water heat exchanger
Fig. 6.7 Flex pre-heating of flow module

2  Engine circuit pump
3  Electric pre-heating
4  Engine circuit circulation pump
5  Pre-heating circuit circulation pump
6  Solenoid valve
TK  Table cooler
6.5 Pipes

The pipes for the cooling water systems must, on principle, be implemented using seamless steel tube. Galvanized steel or copper pipes are not permissible.
Please also see the relevant notes in Chapter 20.

When determining the size of the pipes, the following guide values must be observed:

- Flow speed, system-side pipework: < 3.5 m/s
- The economic speed for fluids in pipes from DN 50 to DN 300 lies in the range of 2 m/s
- For the design volume flow, the flow pressure loss in the cooling circuit must be lower than the discharge pressure head of the pump being used

Piping should be kept short and laid without tension. All components must be firmly fixed in place and, if necessary, vibration-decoupled. Sharp pipe elbows and reducers must be avoided. The materials used for seals, rubber sleeves, and hoses must be resistant to anti-corrosives and to the external effects of fuel and lube oil.

6.6 Ventilation of the cooling systems

The cooling water system must be constantly vented. In plants with diaphragm expansion vessels, the system is vented via the vent valve integrated into the monitoring group or a vent valve which is installed in the pipe. The cooling water pipes must be run in such a manner as to avoid air becoming trapped in the system; if necessary, permanent vents must be provided or bleeding taps need to be planned at the high points. Automatic venting at the engine outlet is recommended, particularly for a constantly vented engine. For safe operation of the cooling system without any pressure surges, it is necessary that the system is ventilated properly and that the air bubbles which might have formed are automatically exhausted.

6.7 Quality of the coolant

For liquid cooled engines, the coolant must be treated and monitored, as otherwise damage may arise due to corrosion, cavitation, or freezing.

The Technical Bulletin for coolant contains comprehensive details of water quality, anti-corrosives, and antifreeze. There is also a list of approved coolant additives from reputable manufacturers. No substances may be used other than those which are approved.
6.8 The heating circuit

In the case of systems with heat recovery, the heat generated by the engine is transferred to the heating circuit. The principal components integrated into the heating circuit on the module side are the cooling water heat exchanger, the exhaust heat exchanger, the circulating pump, the throttle valve and the three-way temperature regulating valve. The heat output from the engine contained in the cooling water and the exhaust gas, and the associated flow rates and temperature differences have been established for the engines in their respective operating modes. The capacity of the circulating pump in the heating circuit is determined by the temperature difference between the flow and return in this circuit. When determining the size of pump, the volume flow increased according to the reserve and the associated higher pressure losses must be taken into account. See also Fig. 6.2 System boundary 4.

The heating circuit must also include a pressure keeping device; generally this is arranged as a collecting system in the return flow.

The heating circuit should be designed in such a way that, independent of the adjusting and regulating processes, the flow, which is described on the heating circuit section (Chapter 6.7, part 1), is ensured without fluctuation of differential pressure (hydraulic disconnection). For this purpose, heat storage tanks are particularly suitable (see Figure 6.6). They decouple the heat generating side from the heat utilizing side.

6.9 Coolant in the heating circuit

The heating circuit is a closed circuit. In this circuit too, a certain water quality must be maintained. Oxygen, chlorides, and hydrogen sulfide in particular promote corrosion in the system. Salts in solution are precipitated as crystals at high heat transfer locations, leading to deposits, which have a negative impact on heat transfer (e.g. boiler scale). There is a risk of crystalline deposits especially at exhaust heat exchangers because of the high water temperatures at the heat transfer points.

These phenomena can be reduced by adding inhibitors to the heating water medium and by selecting suitable materials for the heat exchangers. This must be investigated for each individual application.

If the exhaust heat exchanger is installed in the heating circuit and if the water quality in the heating circuit does not comply to the figures as stated per the Technical Bulletin, it is necessary to provide a separate decoupling circuit with an additional heat exchanger between AWT and heat consumer. Now the exhaust heat exchanger is protected against non-permitted components in the heating water.
Fig. 6.7 P&I flowchart with hydraulic decoupling of heat generation from heat utilization
Legend for P&I flowchart in Fig. 6.7

- MRA10: Genset
- MRN10: Gas control line
- MRE20: Heat utilization
- MRE60: Mixture cooling system
- MRE70: Emergency cooler

- A: Combustion gas
- B: Condensate
- C: Heat storage tank / Hydraulic gate
- D: Boiler
- E: Consumer

- ASD: Exhaust silencer
- AWT: Exhaust heat exchanger
- DV: Throttle valve
- KAT: Catalyst
- KWT: Cooling water heat exchanger
- NK: Emergency cooler
- TK: Table cooler
6.10 Heating circuit design regulations

The regulations for water heating systems and steam boiler systems also apply to the design of the heating circuit.

These include:

DIN EN 12828 Heating systems in buildings (for max. operating temperature up to 105 °C)
When planning or designing CHP systems requiring temperature monitoring/limiting temperatures above 110 °C, it is recommended to consult the local authority responsible for the certification of the system. The favored scope of necessary equipment and the setting of the inspection periods (German Health and Safety at Work Regulations) can be agreed between both parties.

DIN EN 12953 Shell boilers

TRD 604 Sheet 1 Operation of steam boiler systems with Group IV steam generators without constant supervision

TRD 604 Sheet 2 Operation of steam boiler systems with Group IV hot water generators without constant supervision

TRD 702 Steam boiler systems with Group II hot water generators

Depending on the flow temperature in the heating water circuit (90 °C, 100 °C or 120 °C), the appropriate sensors must be installed to protect and maintain the security chain for the exhaust heat exchanger and to secure the heating circuit. The signals from the sensors are processed by the TEM system.
An approval has been granted by the TÜV for the monitoring systems (sensors plus processing of signals via the TEM system), with the result that the individual inspections to be carried out on each system by the TÜV can be completed quickly.
6.11 Emergency cooling circuit

In systems where the dispersal of heat via a heating circuit is not always guaranteed, yet the electrical output of the system must still be available, the heat generated by the engine is dissipated via the so-called emergency cooling circuit. The arrangement of the emergency cooling circuit depends on the system design. Depending on the arrangement of the exhaust heat exchanger or the lube oil cooler for systems with TCG 2032 engines, the emergency cooling must ensure a safe heat discharge from those components even if there is no heat discharge via the heat utilization of the system.

Normally, the heat is dispersed via an emergency cooling heat exchanger integrated into the heating circuit and linked to a table cooler or cooling tower. See Fig. 6.7. When determining the size of pump, the volume flow increased according to the reserve and the associated higher pressure losses must be taken into account.
If the heat produced by the engine cooling water, the exhaust and lube oil (for 2032) is transferred to the heating circuit by one common heat exchanger, the emergency cooler can be implemented directly into the engine cooling circuit without an additional coupling heat exchanger. See Fig. 6.8.

If the heat produced by the engine cooling water, the exhaust and lube oil (for 2032) is transferred to the heating circuit by one common heat exchanger, the emergency cooler can be implemented directly into the engine cooling circuit without an additional coupling heat exchanger. See Fig. 6.8.
Power plants layout

Chapter 7

Fuel system

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7. Fuel system

7.1 Gaseous fuels

The engines operated by combustible gas work as 4-stroke engines following the Otto cycle. The gas-air mixture is fed to the combustion chamber; combustion is then initiated by external ignition via a spark plug. The fuel gases mainly used are natural gas, sewage gas, landfill gas and biogas. Because of their low heat value compared to natural gas, sewage gas, landfill gas and biogas are also known as weak gases. The principal constituents of these gases are hydrocarbons (methane, ethane, butane and propane) as well as nitrogen and carbon dioxide.

The minimum combustion gas characteristics must be maintained according to the data given in the Technical Bulletin for fuel gas.

Operating engines with special gases such as flare gas, mine gas etc. is subject to technical approval from the head office.

7.1.1 Methane number

An important characteristic determining the use of a gas in a gas engine is its knock resistance, i.e. the gas mixture must not self-ignite before ignition, nor must any self-ignition effect cause it to explode suddenly after ignition.

Its methane number gives the knock resistance of a gas. This indicates when a combustion gas in a test engine shows the same knock characteristics as a comparable mixture of methane and hydrogen. To ensure knock-resistant operation with different gases to be used, the methane number must comply with the data sheets. If a gas analysis is available, the respective methane number can be evaluated by the head office. A job card describes the procedure on how to take gas samples. This job card is included in each operating manual.

7.1.2 Accompanying gases / materials

Sewage gases and biogases are primarily accompanied by a proportion of hydrogen sulfide. Landfill gases are mainly contaminated with chlorinated and fluorinated hydrocarbons. As a result, during combustion, sulfuric, hydrochloric and fluoric acids are produced, which damage the crankshaft, the service life of the oil and the entire exhaust gas system. In order to avoid damages to the external exhaust system because of acid temperatures falling below dew point, the exhaust temperatures should not fall below 180 °C. If exhaust temperatures fall to below 180 °C, it is necessary to provide suitable treatment of the combustion gas (e.g. de-sulfuring facilities).
Additionally, landfill gases are often contaminated with gaseous siloxanes. During the combustion in the gas engine, those landfill gases become silicon dioxide and form deposits, which leads to premature wear in the motor, pistons and cylinder liners. A gas treatment is necessary here.

The minimum combustion gas characteristics are outlined in the Technical Bulletin for combustion gas. These data apply only to the use of gases in gas engines. If systems are to be equipped with catalytic converters in the exhaust system, in addition to the minimum characteristics specified for the engine, further restrictions must be taken into account depending on the catalytic procedure selected. In general, a gas treatment has to be planned.

The gases to be used must be carefully tested for pollutants and assessed on the basis of the respective limit values.

### 7.1.3 Water vapor, hydrocarbon vapors, dust in the gas

In order to exclude condensation in the engine under all operating conditions which may arise (including cold starting), the water vapor content in the engine must be limited. The relative humidity of the combustion gas must not exceed 80 % for the lowest gas temperature. Higher humidity levels require approval.

Vaporized higher hydrocarbons lead to a reduction in the methane number. When these vapors condense in the intake tract, the result is heterogeneous droplet combustion. There is a risk of knocking combustion. Also, it is no longer possible to comply with the exhaust emissions cleansing limits.

The dust content (particle size 3-10 μm) of the gas is limited to 10 mg/m³nCH₄ in the combustion gas. Higher dust contents of this grain size lead both to the possibility of deposits in the combustion chamber and to increased contamination of the lube oil, which causes increased wear.

### 7.1.4 Gas cool drying

The combustion gas must be dried for all biogenic special gases and all gases that exceed the limit of 80 % relative humidity. A technically effective variant of this is gas cool drying. Biogas (from renewable raw materials), sewage gas and landfill gas are generally saturated with moisture and hence too damp for direct use. As a side effect of the gas cool drying, pollutants are also washed out of the gas. In particular, water-soluble substances (e.g. ammonia) can be found in the condensate.

The minimum setup for gas cool drying comprises a gas cooling system, a drop separation and a heating of the gas. The gas cooling system, mostly equipped with a cold water chiller, lowers the dew point and hence the absolute moisture content in the combustion gas. The drop separation must ensure that small drops that are carried away by the gas flow are also separated and do not vaporize again in the reheating phase.

Although the reheating does not change the absolute humidity, it does change the relative humidity. The gas can only be dried in this step. The reheating comprises either a water-heated gas heater, a gas-gas heat exchanger, which utilizes the heat of the gas entering the cooling system, or the heat input of a compressor.
Other structures are possible if the function is ensured. Gas lines laid in the ground are not really advisable in the power classes in which the genset manufacturer offers products, because they are not usually suitable for cooling the gas throughout the year.

### 7.1.5 Activated carbon filter

Doped/impregnated activated carbon has proven to be effective for fine desulfurization. Although the higher hydrogen sulfide contents in the biogas can be degraded very reliably and cheaply with biological methods, biological methods are not usually enough to desulfurize the biogas to the extent that an oxidation catalyst with subsequent exhaust heat exchanger can be safely installed in the exhaust tract.

The doped/impregnated activated carbon (frequently potassium iodine) adsorbs the hydrogen sulfide (H₂S) on the carbon surface and oxidizes it there catalytically to elementary sulfur (S). While H₂S as a gas can also be desorbed again (one reason can be warm or damp combustion gas, e.g. due to failure of the gas cool drying), elementary sulfur cannot be desorbed as a solid. As a result of this chemical reaction, the sulfur is therefore bound more strongly on the carbon. The load-bearing capacity of the activated carbon is also therefore higher. Thus the load bearing capacity with good activated carbon in good operating conditions (see manufacturer's notes) is 500 g of sulfur per 1 kg of activated carbon and more. As a result, relatively long operating times of 2000-8000 operating hours can be attained in many biogas systems.

If the activated carbon of the gas flow (flowing speed and pressure loss) is correctly designed and the necessary retention times of the combustion gas in the activated carbon layer are complied with, iodized activated carbon will be able to lower the H₂S flow to the extent that this can no longer be validated with the field measuring instrumentation. This degree of purification is retained over the entire service life. The reactivity of the activated carbon is very high with the result that the activated carbon can theoretically be divided into three layers: the unpolluted activated carbon before the adsorption zone, the adsorption zone in which adsorption occurs (small in relation to the container) and the polluted layer after the active layer. The adsorption zone migrates in the direction of gas flow through the adsorber. At the gas outlet, this migration of the adsorption zone cannot be measured by measuring the H₂S content. It is therefore not possible to determine the pollution of the adsorber at the outlet.

When the adsorption zone reaches the outlet from the adsorber, the H₂S flow rises within a few days to the full input concentration. This process is referred to as break point and must be prevented technically because it progresses rapidly.

One option is to provide permanent H₂S monitoring in the activated carbon layer at some distance from the gas outlet, so that an advanced warning can be generated by sampling the gas from the activated carbon layer. In this way, the activated carbon can be replaced before the break point of the adsorption front by the activated carbon, whereby a certain amount of non-polluted activated carbon has to be disposed of.

Another approach is to reserve two separate activated carbon fillings. A working filter, in which adsorption occurs, and a control filter, which ensures at the break point of the working filter that the gas continues to be finely desulfurized. A continuous H₂S concentration measurement between the two layers makes a
statement concerning the break point of the working filter possible. Upon replacement, the working filter, which is now fully polluted, is disposed of, the control filter becomes the new working filter and the control filter is filled with fresh activated carbon. This can be realized by refilling or by means of a corresponding flap system. If the design of the control filter is large enough (e.g. as large as the working filter), replacement of the working filter can be delayed. In this way, the activated carbon replacement can be synchronized with maintenance work on the engine. The activated carbon must not be able to be bridged with a bypass. Firstly, it is then difficult to demonstrate that this bypass has not been confirmed and that the combustion gas therefore had the required quality. Secondly, short operating times with combustion gas containing H₂S are also sufficient to form sulfuric acid via the exhaust gas catalyst, which condenses in the exhaust heat exchanger. The load-bearing capacity of the activated carbon also depends on the gas humidity and temperature. In general, the gas should be dried (but not be too dry) and should not be too cold either, as the chemical reaction on the surface of the activated carbon is impeded by this. The exact target values can be found in the data sheets of the activated carbons. Owing to the gas states that are better to control, gas cool drying with reheating should take place upstream for conditioning when using activated carbon. The adsorption of silicon-organic hydrocarbons cannot be compared with the H₂S adsorption. These can be found in sewage gas and landfill gas and sometimes also in the combustion gas of biogas systems serving for waste recycling. Non-doped activated carbon filters are used for silicon-organic compounds. They adsorb the pollutants on the surface. However, no chemical reaction occurs there, meaning that the adsorbed substances can be desorbed again. Two further hurdles are: firstly, that the loading capacity for hydrocarbons is not very high and tends to be in the magnitude of percent, and secondly, that not only silicon-organic compounds are adsorbed but all hydrocarbons are adsorbed (although pure hydrocarbons in the engine combustion do not present any problems and would not therefore have to be cleaned). Although no economical system is available for the fine desulfurization, the removal of other pollutants using activated carbon is significantly more complex and expensive with the result that a corresponding estimation has to be made here.

7.1.6 Mixture treatment

The exhaust emissions of the gas engine are regulated by controlling the air-gas ratio. The principal components for the processing of the air-gas mixture before it enters the combustion chamber are the gas control line, the venturi mixer and the throttle valve. Fig. 7.2 shows, among other things, the components for air-gas mixture treatment for lean-burn combustion.
Fig. 7.1  Principle of lean-burn combustion with turbocharging, dual-circuit cooling and combustion chamber temperature control

1  Combustion air
2  Exhaust gas
3  Turbocharger
4  Combustion chamber temperature measurement
5  Cooling water
6  Engine
7  Intercooler
8  LT mixture cooling water
9  Throttle valve
10 Gas
11 Gas control line
12 Mixer with actuator for mixture formation
7.1.7  Gas control line

Gas engines are only permitted to be operated with gas control lines approved by genset producer. Before the gas and air are mixed in the venturi mixer, the pressure of the gas must be reduced to atmospheric pressure. This is performed by the membrane zero pressure regulator in the gas control line. Fig. 7.2 shows, in principle, how the gas control line is designed. The zero pressure regulators have no auxiliary energy supply. At the entry to the gas control line is a manually operated ball valve. This is followed by a gas filter as protection against major impurities. The filter insert comprises a filter mat; filtration rate is approx. 85 % for particles >5 μm. Then come two shut-off valves, which are implemented as solenoid valves or pneumatically operated valves depending on the nominal diameter. When using combustion gases which may contain oxygen, e.g. landfill gas and sewage gas, a deflagration device with temperature monitoring is fitted after the two shut-off valves. Finally, there is the zero pressure regulator. A minimum pressure sensor is always installed in advance of the solenoid valves. Depending on the safety requirements for the system, the gas control lines may be equipped with leakage sensors, intermediate vent valves or maximum pressure monitors.

Zero-pressure gas control lines are operated at a pre-pressure of up to 200 mbar. In the case of higher pre-pressures, either a special design of gas control line or a pre-pressure control line will be required.
7.1.7.1 Pre-pressure control line

The pre-pressure control line reduces the gas pressure below 200 mbar. The principal components of the pre-pressure control line are the ball valve at the entry to the unit, the gas filter, the gas pressure regulator with safety shut-off device (SAV) and the safety blow-off valve (SBV). The safety shut-off valve shuts off the gas supply when the outlet pressure after the pre-pressure control line exceeds the preset limit value. Small pressure surges which occur e.g. when the solenoid valves close in the downstream gas control line are intercepted by the blow-off valve which opens against spring force. Fig. 7.3 shows a pre-pressure control line.
7.1.7.2 Dual gas operation

Each type of gas requires its own gas control line with filtration, shut-off valves and precise pressure keeping. After passing through the gas control lines, the two gases are fed to the engine via separate pipelines or a common pipeline. Because the two gases have different heat values or pre-pressures, this may produce large differences in the nominal diameters of the gas control lines and also as a result in the nominal diameters of the connection lines to the gas mixer on the engine. Special attention must be paid here to ensure that the dead volume between the gas control lines and gas mixer on the engine is kept as small as possible for the respective operating mode. For this reason, it is necessary, especially when there is a large difference in the nominal diameters, that the two gas lines to the gas mixer are laid with the nominal diameter of the respective gas control line and only merge just before the gas mixer. Separate lines are to be provided if the difference in nominal diameters between the two lines is greater than or equal to two nominal diameters.

Dual gas operation is possible only with a multigas mixer (adjustable gap). The changeover from one gas to another takes place automatically when the engine is at a standstill by switching over the solenoid valves at the gas control lines.
In addition, when specially requested, the gas can be mixed before the gas control line. This must be tested and designed in each case.

### 7.1.7.3 Combustion gas system with multi-engine systems and high gas pressures

With multi-engine systems that are connected to a gas network with higher pre-pressures (0.5-10 bar), it is recommended to equip each genset with a pre-pressure and zero-pressure control line. This design has the advantage that the gas collection line to the gensets can be designed with a smaller cross section. Furthermore, the system has a higher stability against pressure fluctuations, which are caused by starting and stopping the individual gensets.

### 7.1.7.4 Notes on installing gas control lines

The gas control line must be arranged in the same room as the gas engine in order to allow the pressure regulator to respond to changes in intake air pressure.

For corrosive gases like landfill gas, biogas or sewage gas, non-ferrous metal (brass) must not be used for parts carrying gas.

Gas pressure regulating devices and pipelines must not be installed under tension. The arrow on the actuator housing must point in the direction of flow. The gas control line must be installed horizontally. Regulators and control devices must, as a matter of principle, be arranged in a normal position.

Blow-off lines from the safety blow-off valve (SBV) must be routed from the engine room into the open air with a sufficient cross section.

The gas control lines must be arranged as close to the gas engine as possible. The maximum distance between the outlet from the gas control line and the inlet into the gas mixer at the engine must not exceed 3 m and there may be a maximum of three 90° elbows in this line.

**Note:** As no further filtration of the gas occurs before the inlet into the gas engine, the line between the gas control line and gas mixer must be cleaned on the inside. See also Chapter 20.1.

In combustion gas mixtures which also contain oxygen as a component (e.g. sewage gas, biogas and landfill gas), backfiring may occur in the gas line. To prevent flames from penetrating the gas supply line, standard gas control lines include long-term fire-resistant deflagration devices with temperature monitoring. Where deflagration devices are installed, the maximum permitted distance between the engine and the gas control line is 40xDN of the gas line. Where the distance is greater, a long-term fire-resistant anti-detonation device must be provided.

The connection to the engine is made via a flexible hose which is laid as a 90° bend, or a specially designed expansion joint which must be installed without tension.

Depending on the system, a gas flow meter may be installed in the feed line to the engines ahead of the control line.
The evaluation units for temperature monitoring at the deflagration device, the SAV in the pre-pressure control line and the gas flow meter must be integrated in the switchgear.

To safeguard the gas engine system, there must be a shut-off device in the gas connection line suitable for manual operation outside of the engine room in a non-hazardous location. This shut-off device must be closed quickly in the event of danger. Remote-operated valves with a permanent auxiliary energy supply (e.g. closing spring) are recommended.

7.1.7.5 Blow-off and breather lines for gas control lines

Lines to atmosphere have to be laid without restriction in the diameter (observe pressure loss) as indicated by the manufacturer of the gas pressure regulator and safety device. Block valves are not allowed in breathing pipes. Blow off pipes must not be combined with breathing pipes into a common pipe. Only pipes to atmosphere are exempted where breathing and safety blow off pipes are already connected inside the device. Fig. 7.4 shows a pre-pressure control line, which does not fulfil this requirement as the blow off and breather pipes are combined into one common pipe. This is not permitted.

The outlets of the discharge lines into the open air have to be far enough away from ignition sources, protected against external corrosion, equipped with protection against blocking and arranged in a way that no leaked gas can penetrate the closed rooms or cause other annoyance or danger.
7.1.8 Gas mixer

Air and gas are combined in the mixer. The mixer is designed as a venturi pipe. The air flows through a nozzle-like constriction and then through a gradually expanding diffuser. The constriction accelerates the flow, which is then slowed down again with minimal loss in the diffuser. The acceleration at the constriction (nozzle) creates an underpressure, so that the gas is automatically drawn in through a gap at the point of minimum cross-section. Thanks to the subsequent deceleration, the pressure then increases again until it is virtually equal to atmospheric pressure, with the result that the mixing process takes place without any great loss of pressure.

The advantage of this type of mixing is that the quantities of air and gas remain in the same proportion to one another even when output is varied by altering the throttle valve position and thereby varying the central air mass flow.

A multi-gas mixer is used with which the gap geometry in the mixer itself can be altered via an actuator. The exact maintenance of the gas-to-air ratio in the mixture depends on the gas pressure ahead of the mixing
gap being equal to the air pressure ahead of the venturi pipe. Fig. 7.5 shows the principle of a gas-air mixer with adjustable gap.

**Fig. 7.5 Multi-gas mixer**

1. Gas inlet
2. Air inlet
3. Gas-air mixture outlet
4. Connection piping to the stepper motor
5. Gas gap

### 7.1.9 Throttle valve

The power output or the speed of the engine is regulated via the throttle valve by means of controlling the amount of the compressed mixture to the engine.

### 7.1.10 Startup of biogas systems

If there is no biogas in the initial phase, alternative gases can be used to start the engine. Permissible alternative gases and engine settings are defined in a Technical Bulletin.

The installed biogas control line is normally a little too big because of the restricted maximum mechanical power and probably a higher heat value $H_u$ of the alternative gas. Therefore, the inlet pressure of the alternative gas must be adjustable in order to achieve as low a pressure level as possible (approx. 5–30 mbar).

It is not possible to install fixed faceplates in order to lower the inlet pressure because the flow rate necessary for engine startup and engine idling is too low.
The zero-pressure regulator must be correspondingly adjusted by an authorized commissioning engineer.

7.2 Notes on installing and maintaining gas systems

7.2.1 Regulations

When installing gas lines and gas system components, increased safety requirements must be complied with. Both when carrying out works on the system and when selecting components, the DIN, TRD, DVGW, etc. regulations must be complied with. The most important ones are listed in the following table:

- DIN 6280-14 “Combined power and heat generation at power plants (CHPs) with reciprocating internal combustion engines – basic principles, requirements, components, designs and maintenance”
- DIN 6280-15 "Combined power and heat generation at power plants (CHPs) with reciprocating internal combustion engines - testing"
- DIN EN 161 “Automatic shut-off valves for gas burners and gas appliances”
- DIN EN 14382 “Safety devices for gas pressure regulating stations and installations – Gas safety shutoff devices for inlet pressures up to 100 bar”
- DIN EN 16678 “Automatic actuators”
- DVGW G 262 “Use of gases from regenerative sources for the public gas supply”
- DVGW G 491 “Gas pressure regulating systems for inlet pressures above 4 to 100 bar”
- DVGW G 493/l “Qualification criteria for manufacturers of gas pressure regulating and measuring systems”
- DVGW G 495 “Operation and maintenance of gas plants”
- DVGW G 600 “Technical regulations for gas installation”
- GUV-R 127 Check “Safety regulations for landfills”
- GUV 17.5 “Safety regulations for waste water treatment plants – construction and equipment”
- BGR 500 Chapter 2.31 “Working with gas lines”

- Following the installation of the gas line and valves, an expert must be commissioned to confirm that the installation has been performed in a technically correct manner and in accordance with the legal regulations.
- Before commissioning the gas control line, a corresponding application must be submitted in good time to the relevant authorities.
7.2.2 Servicing and maintenance

When working on gas lines, among others, the regulations BGR 500 and DVGW worksheet G 495 must be complied with. In particular, it must be ensured that works on the gas system (e.g. opening a gas control line, disassembling and servicing a device) are carried out only when the system is depressurized. Such works must be carried out by trained and qualified specialist personnel only. With regard to service intervals, it is essential to comply with the manufacturer's recommendations for the particular type of operation in terms of visual checks, inspections, function testing and maintenance.
Power plants layout

Chapter 8

Lube oil system

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8. Lube oil system

8.1 Genset

The lube oil systems of the engines are implemented as wet sump lubricating systems. Table 8.1 shows the various lube oil systems used for the different engine series.

Table 8.1

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Wet sump oil pan at engine</th>
<th>Expanded oil tank in base frame</th>
<th>Fresh oil tank in base frame</th>
<th>External oil tank in the plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCG 2016 C</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>TCG 3016</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>TCG 2020</td>
<td>■</td>
<td>■</td>
<td>■</td>
<td>■</td>
</tr>
<tr>
<td>TCG 2032</td>
<td>■</td>
<td>■</td>
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<td>■</td>
</tr>
</tbody>
</table>

All engine series have integral lube oil pumps; the oil is filtered and cooled by either engine-mounted or separate filters and oil coolers.

The external oil coolers and assembly parts have to be designed for a minimum-pressure of 16 bar.

The gensets with engines of the series TCG 2020 can optionally be implemented with an additional oil tank in the base frame. With the series TCG 2016 C there is the option of providing an external oil tank. Due to an increased lube oil volume, considerably increased lube oil service lives are achieved depending on the oil quality and type of combustion gas.

For the TCG 3016 series, the base frame consists of a welded construction with two square tubes parallel to the longitudinal axis of the genset. The tubes are welded to covers at the ends and designed as lube oil tanks. One tank is used as a circulating tank, the other tank is used for collecting fresh oil. When operating the genset, the lube oil refilling of the engine's oil system is carried out via an oil pump mounted on the base frame.

8.2 Plant

For the TCG 2032 engines, the external lube oil circuit components (e.g. heat exchanger) must be arranged at the same level as the genset's foundation or lower in order to prevent the oil from draining back into the oil pan when the engine is at a standstill. For plants with TCG 2032, the external lube oil cooler should be installed as close to the genset as possible so that the lube oil volume is kept as low as possible in the plant system.

Shut-off elements must not be installed in the pipes between the genset and the lube oil cooler. The nominal diameter of the pipes must be minimum DN 125, the nominal pressure of the lines minimum 16 bar. The lube
oil pipes between the genset and the lube oil cooler must be installed below the level of the lube oil outlet connection on the genset or the upper connection of the lube oil heat exchanger as applicable. The lube oil heat exchanger should not be installed in front of the combustion air filters of the engine, because the radiation heat might influence the combustion air temperature. In this case a thermal insulation of the heat exchanger must be provided.

8.2.1 Fresh oil tank

The fresh oil tank must be arranged in a way which prevents it from emptying into the engine due to gravity. In general, lube oil is replenished using a gearwheel pump, which provides a defined filling amount. Compared to refilling with gravity flow, refilling by gearwheel pump is preferred. The size of the supply tank will be dependent on the operating mode of the plant and the associated oil supply required. The minimum recommended size is equal to the quantity required for one oil change plus the amount consumed during two intervals between changes.

8.2.2 Waste oil tank

The minimum recommended size is equal to the quantity yielded by two oil changes.

8.2.3 Service tank

If a service tank is provided for refilling, it should hold sufficient lube oil for approx. 200 oh (e.g. for TCG 2032, approx. 600 dm³).

8.2.4 Container applications

In containers, the available free space might be heavily restricted due to the size of the genset itself and also due the auxiliary equipment. For those applications, the recommendations given above for the size of the oil tanks do not have to be fully adhered to.

8.3 Lube oil treatment

The quality of the lube oil is one of the main criteria determining the service life of the engine components in contact with the oil and hence also the fault-free operation of the plant. Particular attention should therefore be paid to maintaining the lube oil filters and, if appropriate, the separators.

8.3.1 Gas engines

The lube oil filters fitted to gas engines are designed for unlimited operation and no further measures are required on the part of the client to treat the lube oil.
8.4 Lube oil types

Technical bulletins for lube oil contain a list of lube oils available from notable manufacturers and approved for gas and diesel engines. No other lube oils may be used without written approval. Also included in these bulletins are details of lube oil change intervals, used oil analyses and maintenance of the lube oil filters fitted to the engine.

Before commissioning, an analysis of the fresh oil supplied must be compared with the manufacturer's specification.

8.5 Lube oil with biogas applications

Further information regarding the lube oil with biogas applications can be found in the technical bulletin "Optimizing the lube oil management for biogas applications."

8.6 Engine prelubrication

Prelubrication is generally provided for all engine types, as this significantly reduces engine wear. For this purpose, electrically driven pre-lubricating pump modules are used, which in most cases are mounted on the genset base frame. The pre-lubrication pump must be integrated in the lube oil system in such a way that when pre-lubrication is activated, oil flows through all components (filters, coolers) installed between the oil pump and the engine. The capacity and supply pressure of the pump modules must be matched to the respective engine type.

Engine prelubrication takes place immediately before the start when the engines are at a standstill. Optionally, a process called interval prelubrication can be provided, i.e. the engine is prelubricated at preset intervals for a defined period of time.

In the case of plants equipped with gas engines, prelubrication is controlled by the TEM/TPEM system. Prelubrication is inactive when the engine is running.

The TCG 2032 does not have an interval prelubrication and therefore it must be prelubricated before each start.

8.7 Changing and replenishing the lube oil

Lube oil changes must be carried out in accordance with the operating manual for the respective engine, and in the case of gensets in continuous operation, lube oil consumption must be compensated by refilling the system with fresh oil.

When changing the lube oil, make sure that the oil in the system components e.g. pipes, heat exchangers etc. is changed. Drainage options for the lube oil are provided at the lowest points of the system for this.

Depending on the system layout, it is effective to provide a permanently installed or mobile emptying pump.
Fresh lube oil is filled from the fresh oil tank via the top-up pump. This operation can be either manual or automatic. In the case of plants equipped with gas engines, the lube oil replenishment is controlled via the TEM/TPEM system.

Two solenoid valves are installed in series in the lube oil refill line before the engine. When the minimum level in the oil pan is reached, the solenoid valves are opened by the TEM/TPEM system (and/or the top-up pump is started) and the pan is refilled with oil. When the maximum level is restored, the solenoid valves close (and/or the top-up pump is stopped).

When topping up under gravity from the service tank, it must be ensured that the lines are large enough and that the oil does not become too viscous due to low temperatures.

To empty out the oil pan when changing the lube oil, the pressure line from the pre-lubricating pump must be connected to the used oil tank via a three-way valve. To change the lube oil, the three-way valve is switched over and the lube oil is pumped out of the oil pan and into the used oil tank. The top-up pump is then used to fill up with clean oil. The three-way valve behind the pre-lubrication pump is switched back to the "pre-lubricate" position. By activating the pre-lubrication pump, the complete lube oil system is refilled with oil.

Safety and other legal regulations for the use and storage of fresh and/or waste oils must be observed at all costs.
Fig. 8.1 Lube oil system

1. Gas engine
2. Lube oil filter
3. Lube oil cooler
4. Prelubrication pump
5. Oil tank base frame
6. Fresh oil pump
7. Fresh oil tank
8. Waste oil tank
Power plants layout

Chapter 9

Combustion air system

06-2017
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9. Combustion air system

9.1 Definitions

9.1.1 Ambient air

The air of the free environment and the air with which a gas engine is supplied is called ambient air. The ambient air temperature is the temperature measured close to the ground, normally 2 meters above ground level, neither with influence from sunlight nor influence from ground heat or effects of thermal conduction.

9.1.2 Intake air / combustion air

The inlet air or combustion air is provided to the gas engine directly before its combustion air filter. It passes through the plant's ventilation system before reaching the engine's combustion air filters. The ventilation system includes filtering of the air, and depending on the layout of the ventilation system (layout of air ducts and amount of ventilation air), the combustion air may face a certain temperature rise compared to the ambient air temperature.

9.2 Requirements for the combustion air

9.2.1 Combustion air temperature and pressure

In the data sheets, the engine power is indicated as per ISO 3046-1 and the electrical terminal power of the power supply unit as per ISO 8528-1. In both standards, the following standard reference conditions are defined in respect to the combustion air parameters:

- Air temperature: 298 K (25 °C)
- Air pressure: 1000 mbar (100 kPa)
- Relative humidity: 30%

These standard references are sometimes deviated from and special reference conditions defined depending on the engine type for the power data in the Caterpillar Energy Solutions GmbH standard data sheets.

The power is reduced for combustion air temperatures and installation heights diverging upwards from the reference conditions.

The following requirements in respect to the combustion air temperature apply for the start and operation of the engines:

When operating the engines, the combustion air temperatures (minimum / design) have to be kept within the limits as per the data sheets or P&I flow diagrams.
For the start of engines, the following combustion air temperatures have to be maintained in the engine room:

Gas engines with air preheating or wastegate: \( \geq 5 - 10 \, ^\circ C \)

Gas engines without air preheating and waste-gate: \( \leq 10 \, K \) below design temperature as stated per data sheet and/or P&I diagram

TCG 2032 gas engines with air filter / air pre-heating for each cylinder row

The air supplied to the filters/pre-heating must have the same temperature for row A and B

9.2.2 Composition of the combustion air

The normal composition of combustion air is considered to be dry air with a certain amount of steam. The steam content in the air is defined by the relative humidity at a defined air pressure and air temperature. Basically the combustion air must be free of components forming acids or bases; e.g. sulfur dioxide (SO\(_2\)) forms sulfuric acid when combined with water (H\(_2\)O). The main components of dry air at sea level (NN) are given in Table 9.1.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Volume fraction [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen N(_2)</td>
<td>78.084</td>
</tr>
<tr>
<td>Oxygen O(_2)</td>
<td>20.946</td>
</tr>
<tr>
<td>Carbon dioxide CO(_2)</td>
<td>0.035</td>
</tr>
<tr>
<td>Argon Ar</td>
<td>0.934</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>99.999</strong></td>
</tr>
</tbody>
</table>

The remaining 0.001% of the volume fraction are trace gases. This essentially involves the noble gases neon (18 ppm), helium (5 ppm) and krypton (1 ppm).

In the surrounding area of industrial or chemical plants, the composition of the combustion air may face some negative influence from process gases such as, for example, hydrogen sulfide (H\(_2\)S), chlorine (Cl), fluorine (F), ammonia (NH\(_3\)) etc.

The technical bulletin for combustion gas states limit values for the content of "harmful" attending gases like sulfur (S), hydrogen sulfide (H\(_2\)S), chlorine (Cl), fluorine (F) and ammonia. Those given limiting values imply that the composition of the combustion air itself is as per above in Table 9.1, i.e. the combustion air is free of any sulfur, hydrogen sulfide, chlorine, etc. With the given limiting values for the combustion gas, it is possible to deduce limiting values for the content of "harmful" gases in the mixture combustion gas / combustion air and combustion air alone.
Example:
The technical bulletin states the limit for ammonia in the combustion gas at 30 mg/m₃ CH₄. When burning natural gas (100 % CH₄ assumed), for example, 17 standard cubic meters of combustion air are required per cubic meter of natural gas. By use of this ratio, it can be stated that the content of ammonia in the combustion air must not exceed 1.8 (30/17) mg/m₃ in order to keep a condition corresponding to the limit value of 30 mg/m₃ CH₄ given for the combustion gas. If the fuel gas itself contains ammonia too, the limit value for the combustion air must be reduced accordingly.
Similarly, the upper limit values for other "harmful" gases in the combustion air can be calculated. Those values are given in Table 9.2.

Table 9.2

<table>
<thead>
<tr>
<th>Component</th>
<th>Content [mg/m₃ air]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulfur (total) S or H₂S</td>
<td>&lt; 130</td>
</tr>
<tr>
<td>Hydrogen sulfide H₂S</td>
<td>&lt; 135</td>
</tr>
<tr>
<td>Chlorine (total) Cl</td>
<td>&lt; 5.9</td>
</tr>
<tr>
<td>Fluorine (total) F or</td>
<td>&lt; 2.9</td>
</tr>
<tr>
<td>Total chlorine and fluorine</td>
<td>&lt; 5.9</td>
</tr>
<tr>
<td>Ammonia NH₃</td>
<td>&lt; 1.8</td>
</tr>
<tr>
<td>Oil vapors &gt;C5&lt;C10</td>
<td>&lt; 176</td>
</tr>
<tr>
<td>Oil vapors &gt;C10</td>
<td>&lt; 14.7</td>
</tr>
<tr>
<td>Silicon (organic) Si</td>
<td>&lt; 0.59</td>
</tr>
</tbody>
</table>

As a rule, it is not permissible for acid formers such as SO₂, SO₃, HCl or HF (but also other substances) to be in the combustion air. As condensation can occur in the intercooler, especially in hot and humid conditions (e.g. tropics), acid attacks would result here. Acid formers in the exhaust tract are less critical because the dew point is not fallen below here.
Components in the combustion air as mentioned in Table 9.2 might be a reason for shortening the maintenance intervals and they may damage or even destroy emission lowering systems located downstream.
When designing the combustion air system, care must be taken that the air is not drawn from areas in which increased concentrations of these accompanying gases exist or might exist as a result of the equipment installed (e.g. refrigeration systems) or the processes conducted therein.

9.2.3 Cleanliness of the combustion air

Fine sand and dust significantly reduce the service life of the engine if they are directly drawn in by the engine.
The combustion air supplied to the engine must therefore fulfill certain requirements in terms of cleanliness. It is essential to provide air filters which must be implemented as Class F6 to F7 fine dust filters. The mean efficiency of these filters in combating atmospheric dust is specified in DIN EN 779. The separation rates to be achieved with these filter classes are given in Table 9.3:

Table 9.3

<table>
<thead>
<tr>
<th>Particle size (μm)</th>
<th>Separation rate in %</th>
<th>Class F6</th>
<th>Class F7</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;0.5</td>
<td></td>
<td>30</td>
<td>65</td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td>50</td>
<td>85</td>
</tr>
<tr>
<td>1.5</td>
<td></td>
<td>70</td>
<td>95</td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td>80</td>
<td>98</td>
</tr>
<tr>
<td>2.5</td>
<td></td>
<td>85</td>
<td>&gt;99</td>
</tr>
<tr>
<td>3.0</td>
<td></td>
<td>95</td>
<td>&gt;99</td>
</tr>
<tr>
<td>4.0</td>
<td></td>
<td>&gt;99</td>
<td>&gt;99</td>
</tr>
</tbody>
</table>

Mean efficiency (%) as per DIN EN 779: 60 ≤ Eₘ ≤ 80 for Class F6, 80 ≤ Eₘ ≤ 90 for Class F7

Depending on the ambient conditions under which the engine obtains its combustion air, a type of filtration or filter combination must be selected suitable for these conditions.

As already mentioned in Chapter 5 (engine room ventilation), it is required to provide a ventilation system for the engine room including a coarse filter acc. to filter class G3. After the coarse filter, the particle size of the dust in the air is in the range of 1 μm and the dust concentration in the air should be in the range of 0.5 - 1 mg/m³. This concentration corresponds to a dust concentration assumed for the design of combustion air filters of truck engines operating in normal European traffic.

9.2.4 Tropical conditions

In tropical and subtropical areas, the rainfall exceeds the possible atmospheric evaporation for some months of the year. This circumstance causes a high humidity at comparably high mean ambient temperature, about 25 °C average annual temperature. The water content (steam) in the air/combustion air is therefore very high.

When operating high charged combustion engines with charge air cooling or intercooling, there may be condensation of the steam entering the engine together with the combustion air. This condensate may lead to corrosion and wear for engine components like charge air/intercooler, throttle, receiver, valves etc. If, in addition, the combustion air is affected by acid or base-forming attending gases like sulfur dioxide (SO₂), this might lead to accumulation of sulfurous acid. The corrosion for the above-mentioned components will escalate.
Depending on the engine type, a "tropical version" is available under these operating conditions in order to reduce corrosion of the affected components. It is also necessary to prevent the intake air from containing acid formers.

9.2.5 IFE drainage for gensets TCG 2032

For gensets of series TCG 2032, a so-called IFE (Integrated Front End) drainage is offered for use in the tropics. The condensate resulting after cooling of the mixture is dissipated via the condensate drain. The condensate must be disposed of at the plant end. It can be connected either into a condensate collecting tank with corresponding devices for level monitoring and automatic emptying or a duct system outside the machine room. The condensate lines between the genset and condensate collecting tank or duct system must be fitted with a steady downward incline. As a flammable mixture can occur together with the condensate or upon malfunction of a condensate drain, the condensate collecting tank or the duct system must have adequately dimensioned venting to the open air. Gensets with IFE drainage have a detailed installation note in the operating manual.

9.3 Combustion air quantity

The combustion air quantity required for gas engines varies with the composition of the combustion gas and with the combustion air ratio being used. The specific combustion air values given in Table 9.4 apply to the most frequent gas engine application, i.e. operation with natural gas via the lean-burn principle.

Table 9.4

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Combustion air quantity mₗ [kg/kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCG 2016 C</td>
<td>5.2</td>
</tr>
<tr>
<td>TCG 3016</td>
<td>5.2</td>
</tr>
<tr>
<td>TCG 2020(K)</td>
<td>5.2</td>
</tr>
<tr>
<td>TCG 2032</td>
<td>5.0</td>
</tr>
</tbody>
</table>

For precise data, please refer to the specific data sheets.

9.4 Types of filtration for the combustion air

9.4.1 Air filter – Paper/Plastic

In the majority of applications where the air is relatively clean (dust concentration < 1 mg/m³), paper filters are used for air filtration: these may be either plate type filters, pocket or circular air filters. With the series TCG 2016, TCG 3016 and TCG 2020 V12 and TCG 2020 V16 engines, such filters are fitted to the genset with appropriate filter housings. The TCG 2020 V20 is equipped with a separately mounted filter. For the TCG 2032 engines a separately mounted filter housing, containing four filter elements each, is planned per
cylinder row. Depending on the design, this filtering unit also incorporates the intake air pre-heating. The same intake air pre-heating unit may be used optionally with engines of the series TCG 2020, especially with regard to low ambient temperatures.

Because of the sharp increase in pressure loss in the event of contamination, where these filters are used, a negative pressure monitoring facility or vacuum pressure indication must, on principle, be provided. The cleaner the combustion air, the slower the filter gets contaminated. A contaminated filter consumes more energy than a clean filter. Consequently, this leads to a slight increase of the fuel consumption and to an unfavorable operating point of the compressor. In extreme cases, the compressor pumps and the genset cannot be operated safely anymore. The filter needs to be renewed before it leads to a critical operational state.

9.5 Silencer

In the case of air filters installed outside of the genset room, the compressor noise of the turbocharger in particular can be transmitted outside via the air supply pipe, where it makes its presence felt as a high-frequency whistle. In such cases, silencers must be provided in the intake lines, the size of the silencers being determined in accordance with the respective plant.

9.6 Air intake line

Where the air filters are not installed in the engine, an intake line must be installed between the engine and the air filter. Smooth and clean, e.g. painted or galvanized piping must be used for these lines. The line must not bear directly on the engine, i.e. there must be a rubber sleeve or corrugated hose fitted between the air inlet housing and the air line. Sleeves and hoses must not be constricted by bending. All joints in the intake line between the filter and the engine connection must be tightly sealed. If the intake line is routed with a downward incline towards the engine, a water trap must be provided with a drain-off in front of the engine. A useful guide to determining the correct size for the air lines is the air speed in the intake pipe. The air speed should be \( \leq 20 \text{ m/s} \).

9.7 Pressure losses

The air intake system with pipes, elbows, filters, silencers, etc. is itself the cause of pressure losses. The pressure loss occurring at nominal volume flow must not exceed the values laid down for the individual engine series.

These values are given in Table 9.5.
### Table 9.5

<table>
<thead>
<tr>
<th>Engine series</th>
<th>Max. permissible underpressure [mbar]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCG 2016 C</td>
<td>5*</td>
</tr>
<tr>
<td>TCG 3016</td>
<td>5</td>
</tr>
<tr>
<td>TCG 2020(K)</td>
<td>5*</td>
</tr>
<tr>
<td>TCG 2032</td>
<td>5*</td>
</tr>
</tbody>
</table>

* permissible underpressure before air filter

### 9.8 Crankcase venting

Series TCG 2016, TCG 3016 and TCG 2020 and TCG 2032 engines have a closed crankcase venting system, i.e. vapors from the crankcase are directed back to the intake manifold via an oil separator. The separated lube oil is routed back to the engine crankcase.

For the gensets TCG 2032B V16 (4.5 MWel.), an exhaust fan is used to support the crankcase venting system. The extracted gases are returned to the combustion air system after separation of the oil. The system is closed.
Power plants layout

Chapter 10

Exhaust system

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10. **Exhaust system**

The function of the exhaust system is to transfer gases produced by combustion in the engine to the atmosphere. In order to comply with the environmental regulations that apply at the installation site in respect to both the emission of exhaust gases and noise, the exhaust system must be designed to fulfil these necessary requirements.

If the internal combustion process in the engine itself cannot be made to fulfil the local regulations for the emission of exhaust gases, it will be necessary to treat them, e.g. by use of catalytic converters or thermal reactors.

The exhaust noise emissions can be minimized by installing silencers.

Every engine must be fitted with a fully independent exhaust system.

10.1 **Permissible exhaust backpressure**

Besides the exhaust mass flow and the exhaust temperature, the most important design parameter determining the size of the exhaust system is the permissible exhaust backpressure.

Exceeding the permissible exhaust backpressure has a significant influence on performance, fuel consumption and the thermal load of the engine. The exhaust backpressure is measured immediately behind the turbine at full load and must not be exceeded.

Flow resistance in pipes, elbows, expansion joints, exhaust heat exchangers, catalytic converters, silencers, spark arresters, deflection hoods and stacks creates the exhaust backpressure. All resistance must be taken into account when determining the backpressure.

The volume flow dependent resistance in exhaust pipes and elbows can be determined with the aid of the diagram in Fig. 10.1.

For the resistance of components installed in the exhaust system, please refer to the data sheets of these components.

The permissible exhaust backpressures for the individual engine series are listed in Table 10.1.
In designing the exhaust system, the information contained in the data sheets for the individual engine series must be taken into account.

A useful guide to the design of the exhaust system is the speed of the exhaust gas in the exhaust pipe. This should be in the range of 20-35 m/s.

When selecting materials, the temperature increase in the partial load range must be borne in mind.
Fig. 10.1 Flow resistance for exhaust pipes
Legend to Fig. 10.1

VA Exhaust volume flow
TA Exhaust reference temperature
\(\Delta p\) Pressure loss per meter of straight pipe
EL Substitute length for a pipe bend 90°
NW Nominal width of the exhaust pipe in millimeters
R Radius of the bend
d Pipe diameter in millimeters

Example for Fig. 10.1

Specified:
VA = 9000 \( m^3/h \)
Straight pipe: \( l = 10 \) m
Bends: 3 bends 90° with \( R/d=1 \)

Wanted:
\( \Delta p \) of the pipe

Solution:
NW 250
Approx. 44 m/s
\( \Delta p = 0.32 \) hPa / m straight pipe
Substitute length for a bend: 4.95 m

Total pipe length:
\( L_{ges} = 10 + (3 \times 4.95) = 24.85 \) m
\( \Delta p_{ges} = 24.85 \times 0.32 = 8 \) hPa (mbar)

10.2 Exhaust system components

10.2.1 Catalytic converters

All gas engines operate on the lean-burn principle, where thanks to the large surplus of air, the NOx emissions produced by the combustion process are already below the limits prescribed in TA-Luft\(^1\) (NOx \( \leq 500 \) mg/m\(^3\)). Depending on engine type and emissions requirements, it may be necessary to install an oxidation catalytic converter for the further reduction of CO components. The process is particularly economical and, with regard to all aspects of operation, it is both clean and reliable over the long term. Of all

\(^1\) TA-Luft = Technische Anleitung zur Reinhaltung der Luft (Technical instructions on air quality control)
catalytic converter systems, the oxidation type catalytic converter is the most resistant to harmful components in the fuel gas. The catalytic converter must be the first element in the exhaust system.

10.2.1.1 Planning notes for catalytic converters

10.2.1.1.1 Lifting lugs

As the catalytic converter housing can weigh more than 100 kg (especially for big engines), installation should be considered at an early stage of planning. Housings fitted with cones on both sides can be suspended using round slings. In very tight spaces or with other housing shapes, it may also be advisable to provide lifting eyelets. This is important for larger catalytic converter disks, which are installed on the heads of heat exchangers or silencers.

10.2.1.1.2 Insulation

The catalytic converter insulation must be designed in such a way that it can be easily dismounted in order to clean or replace the catalytic converter. This is also beneficial for retightening the flange connections.

10.2.1.1.3 Installation

If not otherwise specifically indicated, catalytic converters can be installed in any position, i.e. horizontally, vertically or diagonally. The flow direction only needs to be taken into account where the housings have different length cones. The inlet cone is usually longer and slimmer than the outlet cone.

When installing a catalytic converter, it is very important that the exhaust gas flow is even through the catalytic converter. If this is not the case, the emission conversion is not at its optimum and the stress on certain parts of the catalytic converter is out of proportion and can cause damage.

To avoid this, two different installation options are available:

Where the unit is to be installed in the exhaust line, the diameter of the line must be adapted to that of the exhaust catalytic converter with the aid of a cone. To ensure that the flow into the catalytic converter is as even as possible, the taper of the cone on the inlet side must be between 10° and 20° (see Fig. 10.2) and the exhaust line must be arranged accordingly (smoothing path). The nominal diameter of the exhaust pipe in front of the taper of the cone on the inlet side must be large enough to ensure an exhaust speed of < 40 m/s.

In case of installation into a silencer or an exhaust heat exchanger, a head pipe with radial exhaust inlet according to Figure 10.3 is required which guarantees an even flow into the catalytic converter. The distance between the center line of the inlet pipe and the flange connection of the catalytic converter should at least
be as long as the catalytic converter's diameter. The nominal diameter of the inlet nozzle before the catalytic converter must be large enough to ensure an exhaust speed of < 40 m/s.

Both the installation into the head pipe of the silencer described and the design with cones serve to achieve as high a homogeneous flow into the catalytic converter as possible. Only a homogeneous flow will achieve the full effect of the catalytic converter.

During operation, the catalytic converters and their housings must remain free of tensions which result from expansion of the exhaust pipes at operating temperature. Expansion joints must be in suitable positions in the exhaust system.
10.2.1.4 Inspection

The catalytic converter should be checked against mechanical damage or contamination at regular intervals. If the engine runs with particle free natural gas and low oil consumption, a yearly inspection is sufficient. For other types of gases or in case of high oil consumption, an inspection is required every 2-6 months. These regular inspections should prevent the system from being shut down.

It must be ensured that good access to the catalytic converter is possible and that inspections can be carried out efficiently right from the planning stage.

10.2.1.2 Installation specification oxidation type catalytic converters

The catalytic converters are supplied complete with hole flange housing for installation in the silencer (head pipe) or as cone catalytic converters with connection flanges for installation in the exhaust line.

Fig. 10.2

- 1 Exhaust flow direction
- 2 Catalyst
- 3 Temperature measuring nozzle
- 4 Exhaust inlet
- 5 Head pipe
- D Catalytic converter diameter
- L Spacing from catalytic converter inlet to center of exhaust inlet

Fig. 10.3

L ≥ D
For the catalytic converter flange connection, the installation specification 1240 2390 UE 0499–41 must be complied with:

10.2.1.2.1 Seals

The seals are designed for operating media temperatures up to max. 650 °C. The seals are made up of segments; one seal set comprises two layers. It is essential to ensure that the segment butt joints are offset between the individual layers. The special properties of the seal in the high temperature range require that these installation specifications be adhered to exactly.

10.2.1.2.2 Screws

The screws are composed of high-temperature resistant steel, which is especially suitable for use at high temperatures.

10.2.1.2.3 Assembly

- The system must be cooled.
- Direction of flow through the catalytic converter; cross bracing for the matrix on the outflow side.
- Clean and check the sealing surfaces.
- Install the catalytic converter and seals, fit the screws with a little high-temperature paste and tighten gently by hand.
- Check that seals are positioned correctly.
- Tighten the screws in alternate groups of 2-6 with a torque wrench to 40 Nm.
- Then tighten all the screws one after another around the perimeter to the nominal torque of 50 Nm.
- The system can now be commissioned.
- For exhaust temperatures above 400 °C, because of the characteristics of the seal, the flange connection must be retightened with the nominal torque after approx. 20 hours in operation. This must be done when the flange connection has cooled down.
- In order to avoid damage to the housing during operation, it is important not to put pressure or tensile stress onto the catalytic converter housing. For this reason, catalytic converter housings always have to be installed stress free.
- As the catalytic converter must be placed as close as possible to the engine for temperature reasons, there are usually no long pipes or other components running from the catalyst. For this reason, a simple expansion joint which can withstand axial and radial forces by means of a pipe elbow is sufficient. If there is a longer pipe after the catalytic converter housing, an additional expansion joint is recommended.
In the event that the catalytic converter housing is installed in the piping, this must be supported by means of one or more columns on the foundation or on a steel structure. Suspensions are also possible. If the catalytic converter housing is installed in the head pipe of a heat exchanger or a silencer by means of a flange connection, it may be necessary to support the head pipe separately by means of a sliding seat. The fixing point in this case must be on the heat exchanger or the silencer. This will not only ensure that the housing is installed free of tension, but also that it can be easily installed and removed.

10.2.1.3 Cleaning the catalytic converter

If the flange connection is opened to clean the catalytic converter, new seals and screws must subsequently be fitted. Remnants of the old seals must be completely removed beforehand. Installation must take place as described above.

10.2.1.4 Operating recommendations for oxidation type catalytic converters

Removing hydrocarbons and carbon monoxide with an oxidation type catalytic converter is a simple method of cleaning the exhaust and this catalytic converter has a wide operating range.

To ensure reliable catalytic converter operation, the following points must be noted:

- Misfiring must be avoided as non combusted fuel in the catalytic converter can lead to undesired after-burning with unduly high exhaust temperatures. Even temperatures below the melting temperature of the supporting material (above 700 °C) cause premature aging. Increasing temperatures may also lead to the catalytic converter being damaged.
- Explosive ignitions in the exhaust pipe can lead to the mechanical destruction of the catalytic converter if the client has not provided explosion flaps.
- To avoid thermal aging, the exhaust temperature on admission to the catalytic converter should be between 400 - 560 °C. Because of the exothermic reaction in the catalytic converter, the temperature of the exhaust is increased. This temperature must not exceed 650 °C. A temperature-monitoring device must therefore be provided after the catalytic converter, which will cut off the fuel supply if this limit is exceeded.
- Low-ash, low-alloy engine oils must be used in order to minimize deposits in the catalytic converter. Blockages of the ducts caused by lube oil incineration ash can significantly impair the functioning of the catalytic converter. Moisture or solvents must be prevented from affecting the catalytic converter; passing through the dew point when starting up and shutting down the plant is an exception to this rule.
- If the catalytic converter is wet, it must be protected from the effects of freezing. The only exception is residual moisture, which comes out from the condensate caused by a cold start at low external
temperatures. For example, an installation above a container is permissible if it is ensured that moisture never gets into the exhaust pipe from outside.

- In the case of biogas systems, the use of oxidation catalytic converters is only possible if the combustion gas has been break-proof fine desulfurized beforehand (see Chapter 9 Combustion Gas). The oxidation catalytic converters even age through the sulfur compounds. However, the greater damage occurs in the exhaust heat exchanger. The oxidation of SO₂ (resulting from sulfur compounds in the engine exhaust gas) to SO₃ shifts the dew point so that the dew point is fallen below here with conventional designs of exhaust heat exchangers, and sulfuric acid condenses correspondingly. This leads to massive contamination of the exhaust heat exchanger and to subsequent acid attacks through to destruction of the exhaust heat exchanger.

- When running on landfill or sewage gas, there is only limited potential for the use of oxidation type catalytic converters, even when a gas purifier is fitted ahead of the engine.

- The following substances are harmful to the catalytic converter and must be avoided in the fuel gas: silicon, silicon products, sodium, calcium, lead, bismuth, mercury, manganese, potassium, iron, arsenic, antimony, cadmium; under certain circumstances also compounds of chlorine, sulfur and phosphorus; as well as organic and inorganic compounds.

- The catalytic converter should be installed before the silencer, in order to prevent obstruction of the catalytic converter due to the detachment of absorbent wool. Obstruction of the catalytic converter will lead to an increase in the exhaust backpressure and the reduction of pollutants becomes worse. It is not easy to remove the wool from the channels of the catalytic converter. On the other hand, installation after a pure reflection silencer without sound-absorbent wool is permissible provided that exclusively stainless steel parts are used.

- In order to protect them against overheating, the catalytic converters should only be installed in the exhaust system when the engine has been adjusted and is running trouble free. This applies to both initial commissioning and subsequent maintenance work.

- Sulfur in the form of SO₂ has hardly any influence on the catalytic converter at temperatures over 420 °C. However, it must be ensured that some of the SO₂ is oxidized to SO₃ in the catalytic converter. So if the dew point in the exhaust system is undershot, sulfurous acid is generated for SO₂ and for SO₃. Sulfuric acid. The dew point is approx. 140 °C.

- Even though solid substances, which are found in the exhaust gas flow and deposited on the catalytic converter, will not directly damage the catalytic converter, the emission reduction will be degenerated over time. The active surface will be partially covered. If there is an increase in the amount of deposits, the individual channels will become blocked. The exhaust gas then has to go through the channels still open. Therefore, the flow velocity and the emission reduction will decrease. The increase of the backpressure results in a power reduction, or worse still, the shut down of the engine. This can be monitored by measuring the differential pressure.
10.2.1.5  Limit values for exhaust composition

The life expectancy of the catalytic converter largely depends on the concentration of catalytic converter toxins. Therefore, the exhaust should be free from the known compounds which cause damage to the catalytic converter, e.g. silicon, silicone, sulphur, phosphorus, arsenic and heavy metals. The concentration of catalytic converter toxins should not exceed the following values:

<table>
<thead>
<tr>
<th>Catalytic converter toxin</th>
<th>Warranty period 8000 operating hours or 1 year</th>
<th>Warranty period 16000 operating hours or 2 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicone</td>
<td>0 µg / Nm³</td>
<td>0 µg / Nm³</td>
</tr>
<tr>
<td>Silicon</td>
<td>0 µg / Nm³</td>
<td>0 µg / Nm³</td>
</tr>
<tr>
<td>Arsenic</td>
<td>&lt; 1 µg / Nm³</td>
<td>&lt; 1 µg / Nm³</td>
</tr>
<tr>
<td>Mercury</td>
<td>&lt; 1 µg / Nm³</td>
<td>&lt; 1 µg / Nm³</td>
</tr>
<tr>
<td>Lead</td>
<td>&lt; 2 µg / Nm³</td>
<td>&lt; 1 µg / Nm³</td>
</tr>
<tr>
<td>Cadmium</td>
<td>&lt; 10 µg / Nm³</td>
<td>&lt; 10 µg / Nm³</td>
</tr>
<tr>
<td>Zinc</td>
<td>&lt; 100 µg / Nm³</td>
<td>&lt; 50 µg / Nm³</td>
</tr>
<tr>
<td>Bismuth</td>
<td>&lt; 1 µg / Nm³</td>
<td>&lt; 1 µg / Nm³</td>
</tr>
<tr>
<td>Antimony</td>
<td>&lt; 1 µg / Nm³</td>
<td>&lt; 1 µg / Nm³</td>
</tr>
<tr>
<td>Hydrogen sulfide</td>
<td>&lt; 10 mg / Nm³</td>
<td>&lt; 5 mg / Nm³</td>
</tr>
<tr>
<td>Sulfur</td>
<td>&lt; 10 mg / Nm³</td>
<td>&lt; 5 mg / Nm³</td>
</tr>
<tr>
<td>Ammonia</td>
<td>&lt; 100 mg / Nm³</td>
<td>&lt; 100 mg / Nm³</td>
</tr>
<tr>
<td>Phosphorous compounds and halogens</td>
<td>&lt; 5 mg / Nm³</td>
<td>&lt; 1 mg / Nm³</td>
</tr>
<tr>
<td>Chlorine</td>
<td>&lt; 10 µg / Nm³</td>
<td>&lt; 10 µg / Nm³</td>
</tr>
<tr>
<td>Sodium</td>
<td>&lt; 10 µg / Nm³</td>
<td>&lt; 10 µg / Nm³</td>
</tr>
<tr>
<td>Calcium</td>
<td>&lt; 10 µg / Nm³</td>
<td>&lt; 10 µg / Nm³</td>
</tr>
<tr>
<td>Manganese</td>
<td>&lt; 10 µg / Nm³</td>
<td>&lt; 10 µg / Nm³</td>
</tr>
<tr>
<td>Potassium</td>
<td>&lt; 10 µg / Nm³</td>
<td>&lt; 10 µg / Nm³</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt; 10 mg / Nm³</td>
<td>&lt; 5 mg / Nm³</td>
</tr>
</tbody>
</table>

Source: Air Sonic
10.2.1.6 Oxidation catalytic converters for bio- and sewage gas engines

Most manufacturers will not cover their catalytic converter for warranty if the engine is operated with landfill or sewage gas. The terms of warranty need to be clarified in the design stage in case a catalytic converter should be installed for bio and sewage gas operation.

The problem with these systems is that no operator can forecast what pollutants will be in the exhaust in the coming weeks, months or years.

Even a comprehensive analysis, which shows low pollutants, is only a momentary record. In most cases, the exhaust is not tested for all possible pollutants, and on the other hand, the composition may already be different after a few days.

This is also confirmed by the fact that similar sewage gas systems do achieve different life expectancy for the same catalytic converters.

For biogas, the situation is a little different. In special cases, it can be considered whether a warranty can be granted. However, an accurate exhaust analysis and accurate description of the plant are necessary.

Without a sufficient gas cleaning system, no guarantee for the pollutant conversion of the catalytic converter will be given for sewage gas, landfill gas and biogas.

10.2.2 Exhaust silencer

The task of an exhaust silencer is to dampen the exhaust noise produced when the engine is operating to a level commensurate with the respective surrounding environment. The silencers used take the form of reflection, absorption or combination type silencers. Reflection silencers achieve their maximum effect in the lower 125-500 Hz frequency range, whilst absorption silencers are most effective in the 250-1000 Hz range.

In the case of combination silencers, the first part is designed as a reflection silencer and the second as an absorption silencer. The combination silencer unites the characteristics of both silencer types and so achieves a significant silencing effect over a broad frequency range.

In cases in which the required level of silencing cannot be achieved with a combination silencer, additional absorption silencers must be fitted after the combination silencer. An expansion joint must be installed between the silencers to insulate against structure-borne noise.

See also Chapter 4.3, Noise issues.

The exhaust silencers go through heat expansion at operating temperature. Fixed and loose supports must be provided accordingly during planning.

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3 Source: Air Sonic
10.2.3 Exhaust heat exchanger

Exhaust heat exchangers are used to recover the heat from the exhaust. These exhaust heat exchangers are built in accordance with the European pressure vessel guideline (PED 2014/68/EU). The testing procedures are based on national regulations, for example the TRD⁴ and AD leaflets⁵ of the manufacturing country.

In CHP, the exhaust heat exchangers are usually made of stainless steel (1.4571). For natural gas applications, the exhaust temperature at the heat exchanger outlet is normally 120 °C. To prevent corrosion, it must be ensured that the exhaust gas does not fall below the dew point.

In all systems where the exhaust heat exchangers are mounted higher than the engine, a continuous condensate drain / separator generally has to be installed. This will prevent water from finding its way into the engine via the exhaust line in the case of a water breakthrough in the exhaust heat exchanger.

In the case of systems which are operated on landfill gas or sewage gas, the increased content of sulfur, chloride, hydrochloric acid and hydrofluoric acid in the exhaust must be borne in mind when selecting materials. These components have a highly corrosive effect and can even damage stainless steel exhaust heat exchangers.

If there is a risk of increased concentration of chlorine or other halogenated components in the combustion gas, exhaust tubes made of thick low alloyed boiler steel are preferable to stainless steel tubes due to the danger of local pitting and stress corrosion. This steel is less sensitive to this type of corrosion. In order to avoid wide-spread corrosion, it is absolutely necessary to prevent condensation of the above mentioned acids and water out of the exhaust gas. In this case, the exhaust temperature should be > 180 °C.

For systems with sulfur in the combustion gas and with an oxidation catalytic converter pre-connected to the exhaust heat exchanger, a fine desulfurization of the combustion gas must be carried out. Sulfur dioxide contained in the exhaust gas is oxidized into sulfur trioxide in the oxidation catalytic converter. When cooling the exhaust gas in the connected exhaust heat exchanger, sulfur trioxide reacts with water and forms concentrated sulfuric acid. Concentrated sulfuric acid is highly corrosive and can quickly cause the destruction of the exhaust heat exchanger. Furthermore, operating faults may be caused by an increased exhaust backpressure, which has been created by sulfurous deposits. Effective protection for this system design can only be guaranteed with a fine desulfurization of the combustion gas.

The water qualities in respect to the heating requirements must be complied with (Technical Bulletin for coolant).

In large heating circuits, complying with the minimum requirements for the water quality may pose a problem. In this case, the installation of a small closed decoupling circuit between exhaust heat exchanger and heating circuit is urgently recommended. In the technical bulletin for cooling water, a chloride content smaller than 20 mg/l is required for the coolant in the heating circuit. For increased chloride ion content and

⁴ TRD = Technische Regeln für Dampfkessel = Technical Directions for Steam Boilers
⁵ AD = Arbeitsgemeinschaft Druckbehälter = Pressure Vessels Working Party
increased flow temperatures in the heating circuit, the stainless steel pipes usually used in the exhaust heat exchangers are subject to stress corrosion cracking, which can lead to the exhaust heat exchanger being damaged. Therefore, providing there are no contrary requirements on the exhaust side, an exhaust heat exchanger with water-bearing components (pipes, pipe plate and casing) made of normal steel should be provided for decoupling the exhaust heat exchanger in the heating circuit and water temperatures > 110 °C. (Also see Chapter 6.8 “The heating circuit” & 6.9 “Coolant in the heating circuit”)

The exhaust heat exchangers go through heat expansion at operating temperature. Fixed and loose supports must be provided accordingly during planning.

10.2.4 Exhaust components in biogas systems

The following items must be considered when selecting exhaust systems for biogas systems:

- For biogas systems with a maximum permissible sulfur content (total) of < 2.2 g/m³n or a H₂S content of < 0.15 % volume in the biogas, the exhaust gases should not be cooled below 180 °C. The limit values must be maintained permanently. In this case an oxidation catalytic converter must not be used.
- To cool down an exhaust to 120 °C, in addition to the minimum characteristics of combustion gases in gas engines, the sulfur content of the biogas has to be limited to < 0.1 g/m³n or the H₂S content to < 70 ppm.
- When using oxidation catalytic converters, a fine desulfurization of the combustion gas must be carried out. This must always completely remove the H₂S (validation limit of the field measuring instrumentation, but maximum 5 ppm H₂S). This can be implemented technically with an activated carbon adsorber with doped/impregnated active carbon.
- In biogas plants, the exhaust silencers are to be preferably mounted ahead of the exhaust heat exchanger, as the risk of acid condensation is lower at higher exhaust temperatures.
- Furthermore, a continuous condensate drain has to be installed. The condensate drain has to be checked at regular intervals during operation and must be protected against freezing in the winter.
- The exhaust side of the heat exchanger must be cleaned regularly.
- All components carrying exhaust gas must be insulated due to the risk of condensation; this is imperative outdoors, too.

10.2.5 Exhaust flaps

For most applications, the layout of the exhaust system is individual for each engine. In these systems, exhaust flaps are used for by-passing exhaust components. With multi-engine installations where engines must be connected to one common exhaust line, exhaust flaps must be provided for the disconnection of the individual engine from the common exhaust line. This is, for example, the case if the exhaust gas of several engines is combined for the operation of a common absorption chiller.
Exhaust flaps are not completely tight in the fully closed position, there is always a small amount of leakage flow.
The requirements concerning the tightness of exhaust flaps have to be considered with the individual application demands (e.g. TRD 604 Sheet 2).

### 10.2.5.1 By-passing of components in the exhaust system

For by-passing exhaust components such as, for example, exhaust heat exchangers and/or steam boilers, exhaust flaps are used. The flaps' drive is via an electric motor or pneumatic actuator. They simply have an open/close function and no control function. Preferably, flap combinations are used, i.e. there is only one drive mounted on one of the flaps whereas the other flap drive is via a reverse-acting mechanical link.

### 10.2.5.2 Multi-engine installations with common exhaust line

For multi-engine plants with a common exhaust manifold, exhaust gas must be prevented from uncontrolled backflow to the engines currently not in operation. Uncontrolled backflow of exhaust gas will cause corrosion in this engine. There are different possibilities to avoid backflow of exhaust gas by a respective arrangement of exhaust flaps. They are described in the following.

**Exhaust flap arrangement with separate exhaust pipe**

With this system, an exhaust flap is arranged behind the engine. Using a by-pass flap combination, the exhaust gas is either led to the common exhaust manifold or to the open air via a separate exhaust pipe (see also Figure 10.4). When the engine is not in operation, the exhaust flap behind the engine (flap 1) and the flap in the pipe branch to the common exhaust manifold (flap 2) are closed, whereas the flap in the pipe branch to the open air (flap 3) is open. In the common exhaust manifold, there will be an overpressure when the other engines are running and, as a consequence, there will be a slight leakage flow via flap 2 into the space between. As the leakage flow is comparably small and free cross section to the open air comparably large (flap 3 open), the leaking gas will go to the open air and the engine will be protected by closed flap 1. Before starting the engine, the exhaust flap 1 behind the engine will be opened, in the first instance the exhaust flow is via flap 3 to the open air. When the engine is started up, the exhaust path to the open air is closed and the path to the common exhaust pipe is opened at the same time by switching the exhaust by-pass flap combination.

This arrangement has the following advantages:

- Each engine can be operated individually, i.e. it is independent of the conditions in the common system.
- The engine can be started without exhaust backpressure.
- With electricity-led operation, the exhaust heat can be adjusted to the active demand by switching the by-pass to the open air.

This arrangement is highly recommended with several engines connected to one common exhaust system.
Fig. 10.4 Common exhaust system with by-pass to the open air

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Exhaust flap 1</td>
</tr>
<tr>
<td>2</td>
<td>Exhaust flap 2</td>
</tr>
<tr>
<td>3</td>
<td>Exhaust flap 3</td>
</tr>
<tr>
<td>4</td>
<td>Bypass to open air</td>
</tr>
<tr>
<td>5</td>
<td>Exhaust manifold</td>
</tr>
<tr>
<td>6</td>
<td>Gas engine</td>
</tr>
</tbody>
</table>

**Exhaust flap arrangement with air lock**

With this system, there are two exhaust flaps arranged one after another in the exhaust pipe to the common exhaust manifold. The flaps can be opened and closed via an actuator. The sealing air line is connected in the space between both flaps. The supply of sealing air is via a fan with a shut-off flap downstream (see also Figure 10.5).

When the engine is not running, both flaps (flap 1 and 2) are closed and sealing air is blown into the space between the flaps. The pressure of the locking air must be higher than the maximum pressure in the exhaust manifold and the volume flow of the sealing air must be greater than the leaking rate of the exhaust flaps. There is no possibility of exhaust backflow to the engine when it is not running.

Before starting the engine, both exhaust flaps must be opened, flap 3 after the fan will be closed and the sealing air fan will be switched off. The engine has to start at the increased exhaust pressure level existing in the exhaust manifold.

Advantage: No additional exhaust pipe to the open air is necessary.
Exhaust flap arrangement with intermediate venting

With this system, there are two exhaust flaps arranged one after another in the exhaust pipe to the common exhaust manifold. The flaps can be opened and closed together via an actuator. The ventilation line is connected in the space between both flaps. The leakage gas in the space between the exhaust flaps is extracted by an extractor fan with a shut-off flap upstream and routed to the open air (see Figure 10.6). When the engine is not running, both flaps (flap 1 and 2) are closed and a slight negative pressure is maintained in the space between the exhaust flaps. The leakage gas flowing via the exhaust flaps is routed to the open air via the extractor fan. Leakage gas flowing into the engine when not running is avoided. Before starting the engine, both exhaust flaps must be opened, flap 3 before the fan will be closed and the extractor will be switched off. The engine has to start at the increased exhaust pressure level existing in the exhaust manifold.

Disadvantage: A separate pipe to the open air must be provided, but the cross section is comparably small in relation to a full-sized exhaust line as per Fig. 10.4 above.
Fig. 10.6  Common exhaust system with intermediate venting

1  Exhaust flap 1
2  Exhaust flap 2
3  Air flap
4  Exhaust manifold
5  Gas engine
10.2.6 Laying exhaust pipes

Because of the relatively high exhaust temperatures, heat expansion is quite considerable (approx. 1-1.5 mm/m and 100 °C).
To avoid unacceptably high stresses in the exhaust pipes, expansion joints must be fitted at suitable locations to compensate for the heat expansion in the pipes and components. Depending on how the exhaust line is laid, the supports should be fixed and moveable. They must not be fixed on the exhaust turbocharger or the engine. The first fixed point must be located directly after the expansion joint at the turbocharger outlet. In particular, components integrated in the exhaust system such as heat exchangers, catalytic converters, silencers, etc. must be protected against stresses arising from the expansion of the exhaust pipes by fitting expansion joints on the inlet and outlet sides. The exhaust expansion joints must be installed in accordance with the manufacturer's directions (permissible axial and lateral offset must be complied with). Because of the high operating temperatures, the exhaust system is permanently provided with insulation. When installing pipes outside, a contact protection is only sufficient for exhaust pipes after exhaust heat exchangers.

10.2.7 Additional hints for the design of exhaust heat exchangers and silencers

10.2.7.1 Lifting lugs

For better handling of the components during installation, lifting lugs should be provided.

10.2.7.2 Structure-borne noise

When affixing the unit, it is important to note that where appropriate, sound-technology aspects also play a role here. In this case, it must be ensured that minimal sound is transmitted to other components. For this reason, vibration dampers are installed in the feet or the mounting. This applies equally to standing as well as suspended versions. As the piping and the catalytic converter housing are insulated for temperature reasons, no further sound insulation of these components is necessary in the majority of units.

10.2.7.3 Installation

When installing catalytic converter housings, exhaust heat exchangers and silencers, careful handling is essential to ensure that protruding parts such as probes, feet, etc will not be damaged. This inevitably leads to damage to the housing and components. Mounting feet are only for taking the design load. The client is requested to find out about the installation situation, preferably when placing the order. If a housing has sliding supports which are not directly fixed to concrete or steel frames but mounted to a sliding plate, it must be ensured that a lubricant is used between foot and sliding plate. Periodic checks should be conducted to ensure that enough lubricant is always present during operation.
10.2.7.4 Cleaning of exhaust heat exchangers

When installing the exhaust heat exchangers, enough free space must be considered for cleaning purposes.

10.2.8 Exhaust stacks

Especially in the vicinity of residential areas, it is necessary to avoid impermissible engine exhaust emissions. Stacks are used to transport the exhaust gas up to a high level in the atmosphere.

The exhaust stacks must be insulated to avoid condensation in the exhaust system. The speed of the exhaust gas in the stack should be between 15-20 m/s. Above 20 m/s, there is a risk of resonance vibrations in the gas column. A high outlet speed leads to a dynamic increase in effective stack height and improves the dispersal of the gases, but it also increases the flow noise.

The draught effect of the stack, which is dependent on stack height, lessens the backpressure in the exhaust system. However, installing deflector hoods at the mouth of the stack can partially or even entirely offset the stack draught, with the result that, in a worst-case scenario, the backpressure of the stack must also be regarded.

Exhaust stacks must be equipped with permanent drainage and weather-induced contamination (e.g. rain, snow) must be excluded.

All components must be provided with a permanent drainage facility at their lowest point. Condensate disposal must be clarified on a case-by-case basis and, where necessary, it must be directed to a neutralization facility.

10.3 Deflagrations in the exhaust system

All technically feasible prerequisites are created for gas engine gensets from Caterpillar Energy Solutions in order to ensure the highest degree of safety against deflagrations in the exhaust system. The following conditions can be viewed as the most critical for the occurrence of deflagrations:

- The engine does not start and, as a result, the gas-air mixture gets into the exhaust system.
- The ignition fails because of a technical defect or the ignition is switched off in a fault shutdown. In both cases the gas/air mixture flows into the exhaust system.

The components, functions and procedures that prevent the unrestricted transport of unburnt gas/air mixture into the system are described in the following:

10.3.1 Gas control lines

All gas control lines have two separate, electrically or electro-pneumatically operated, airtight shut-off valves that are closed when the genset is shut down. An optional leakage check establishes each time before the
gas genset is started as to whether the valves were secure whilst the genset was at a standstill. During this time no combustion gas can get into the exhaust system. The shut-off valves are controlled separately in a safety-oriented manner.

**10.3.2 Starting sequence**

During the gas engine’s start phase, the engine’s mixture system and exhaust system are flushed with air by rotating the starter without supplying any combustion gas (shut-off valves in the gas control line closed). After pre-flushing and reaching a specified limit speed, the ignition is switched on and checked for proper operation. Then and only then are the shut-off valves of the gas control line opened, the gas/air mixture entering the engine sparked and the gas engine genset accelerated to the rated speed.

**10.3.3 Start failure and start retry**

In case of a start failure, e.g. fault in the plant's gas supply (bad gas or gas pressure too low), unburnt gas/air mixture can get into the exhaust system. However, this mixture is then outside of the ignition limit and can be considered non-combustible, as even the enabled high-energy ignition system could not make it burn. In this case, there is also no speed increase of the gas engine to the rated speed, which causes the shut-off valves in the gas control line to close after the time specified in the control system expires. The engine comes to a stop and conveys air into the mixture and exhaust systems during this time. The ignition remains switched on until the genset is shut down. If the start is repeated, more air is initially conveyed into the exhaust system though the flushing process described above, which continues to dilute the non-combustible mixture from the previous start attempt.

It must be ensured that the zero pressure controller of the gas control line is adjusted correctly and not set improperly. The regularly prescribed maintenance work on the gas mixer must be carried out so that it does not lock. The TEM/TPEM control system issues a warning to show that maintenance of the gas mixer is required.

Only two repeats of the start-up can be carried out. If the gas engine does not start after the second repeat of the start-up, a fault alert is triggered by the TEM/TPEM control system. The gas engine genset can no longer start automatically and in order to start again manually, the fault must be manually acknowledged. Before acknowledging the fault, debugging has to be resolved.

The temperature of the engine and exhaust system will continue to be taken included in this consideration. If the gas engine and exhaust system are cold, the temperature of the gas/air mixture is at a level similar to the ambient temperature. At these temperatures the chance of a deflagration is excluded (see also 10.3.8). Therefore the probability of a deflagration of the unburnt gas/air mixture starts to become greater if the gas engine is warm and the exhaust lines are hot.
10.3.4 Normal stop of the gas engine genset

For these shutdown processes, the shut-off valves of the gas control line are firstly closed. The ignition plant remains in operation so that the unburnt mixture still in the system is burnt inside the engine. The rotational energy of the rotating masses causes the speed to decrease slowly and finally causes the gas engine genset to reach a standstill. The throttle valve is left completely open during this phase. This ensures the best possible flushing of the lines with air.
10.3.5 Ignition fault in operation

When the gas engine genset is operating, the function of each individual spark plug is monitored. If a spark plug fails, the power of the gas engine genset is reduced and once the generator switch is opened, the gas engine is stopped. During this time, unburnt gas/air mixture gets into the exhaust system via the cylinder with the faulty ignition. This is mixed with the exhaust from the other cylinders and diluted to the point that the combustion air ratio is far outside the ignition limit. The carbon dioxide and water contained in the exhaust gas pushes the ignition limit further up.

If the ignition system fails as a result of a technical fault, the genset is immediately shut down by closing the gas valves in the gas control line. In this case, the mixture lines on the gas engine are still filled with the gas/air mixture. This mixture is then moved into the exhaust line as a "cold" lean mixture at a combustion air ratio of approx. 1.8. When the genset continues to run until standstill, the mixture and exhaust lines are flushed with "cold" air.

10.3.6 Mixture and air quantities

- Starting a cold engine
  Before starting the genset, i.e. before opening the gas valves, approx. 1.5 times the total swept volume of air is flushed through the genset. If the engine does not start, i.e. by the time when the control system detects a start failure and cancels the start, 22 times the total swept volume of the gas/air mixture is conveyed into the exhaust system.
  When the genset runs until standstill, an additional total swept volume of air is flushed into the exhaust system while the genset is cold.

- Starting a warm engine
  A warm engine has a higher starter speed and the air volume for flushing before start up heats up on the hot exhaust lines. A flushing volume of approx. 3.5 times the total swept volume is flushed through the system. If the engine fails to start, approx. 60 times the total swept volume of the gas-air mixture is fed into the exhaust system until the start procedure is aborted. When the warm genset comes to a stop, the exhaust system is flushed through with approx. 3 times the total swept volume of air.

- Ignition fault at full load
  Although the shut-off valves of the gas control line are immediately closed in the event of an ignition fault, the “cold” mixture present in the mixture lines gets into the hot exhaust system with a combustion air ratio of approx. 1.8 and is heated up there by the hot surfaces. The quantity of the mixture is approx. 40 times the total swept volume. When the gas genset runs until standstill, the mixture and exhaust lines are flushed with “cold” air, which also warms up on the hot surfaces of
the exhaust system. The quantity of air flushed through is approx. 100 times the total swept volume.

10.3.7 Exhaust gas temperatures

Gas engine gensets from Caterpillar Energy Solutions are operated with low exhaust gas temperatures because of the high electrical efficiency. The exhaust gas temperatures reach approx. 400 °C at full load and approx. 470 °C at 50 % partial load when operated with natural gas.

10.3.8 Auto-ignition conditions

The ignition temperature of natural gas as known from the literature is approx. 570 °C at a combustion air ratio of 1.8. This temperature applies to methane and natural gases H with a high proportion of methane. The ignition limits may be lower for natural gases with longer-chain hydrocarbons or hydrogen content.

10.3.9 Risk of a deflagration

In case of faults when starting and operating the gas engine genset, it cannot always be avoided that the gas-air mixture is able to get into the exhaust system. When starting the engine when cold, there is no risk of a deflagration, since there is no ignition source (hot surface). Therefore, faults in operating conditions and the hot exhaust system should be considered critical. As previously mentioned, the exhaust gas temperatures are below 500 °C and are therefore significantly below the auto-ignition temperature of 570 °C for natural gas H at a combustion air ratio of 1.8. With each fault, “cold” mixture or cold air will continue to be conveyed into the exhaust system as described above, leading to a further decrease in the temperature and increasing the distance from the auto-ignition temperature. The auto-ignition of the mixture on hot surfaces is unlikely from a technical perspective and in the case of correct operation of the gas engine genset.

10.3.10 Ignition sources in the exhaust system

In a normal exhaust system, there are in fact only two possible ignition sources:

- Hot surfaces of an oxidation catalytic converter
- Ignition sparks in the exhaust system from electrostatic discharge

10.3.10.1 Oxidation catalytic converter

Potential ignition of the combustible gas/air mixture on the hot surfaces of an oxidation catalytic converter can be limited. To do this, the catalytic converter must be installed in the area of the exhaust system that is definitely pressurized with air in the start and stop procedures described above. Therefore, the oxidation
catalytic converter is installed as the first component of the exhaust system after the gas engine. The length of the exhaust pipe from the exhaust outlet to the oxidation catalytic converter is supposed to be as short as possible and must not exceed 7 meters. With a 7-meter long exhaust pipe in the exhaust pipe nominal diameter used for the respective series, the ratio of exhaust pipe volume before the oxidation catalytic converter and the total swept volume is in the range of 10-20. This ensures that the exhaust system up to the oxidation catalytic converter is well flushed with cold air.

10.3.10.2 Electrostatic discharge

Differences in potential may arise between individual components of the exhaust system or even between the pipes installed in the exhaust system because of electrostatic charge and those differences may under some circumstances be discharged in a spark. If spark discharge and the gas/air mixture appear simultaneously, there is an increased risk of a deflagration. Therefore, it is also absolutely necessary for the exhaust system that all components and pipes are connected to potential equalization.
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Chapter 11

Compressed air system

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11. Compressed air system

Some engine models are started with compressed air. In this case, the engine is started with a compressed air starter which acts on a flywheel gear rim. Table 11.1 shows the starting systems employed for the various series.

Table 11.1 Starting systems

<table>
<thead>
<tr>
<th>Engine type</th>
<th>Compressed air starter via gear rim</th>
<th>Electric starter</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCG 2016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCG 3016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TCG 2020(K)</td>
<td>[Standard]</td>
<td></td>
</tr>
<tr>
<td>TCG 2032</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 11.1 shows a starting air system for an engine with a compressed air starter.

1 Compressor
2 Oil separator
3 Pressure gauge
4 Non-return valve
5 Compressed air bottle
6 Condensation deflector
7 High-pressure shut-off valve
8 Dirt trap
9 Pressure regulator
10 Safety valve
11 Starting valve
12 Starter
13 Control valve
14 Pressure switch/Compressor ON/OFF
15 Pressure switch/Alarm min. pressure

The compressor (1) fills the compressed air bottle (5), which is equipped with a water separator (6), via the non/return valve (4) and the oil separator (2). The filling pressure of the bottle can be read from the pressure gauge (3). The high-pressure shut-off valve (7) and the dirt trap (8) provide the starter valve (11) with
compressed air. When the engine starts, the starter valve is opened by the control valve (13) and the starter (12) is pressurized with compressed air. The engine starts.

11.1 Compressed air system components

11.1.1 Compressors

Redundant diesel or electric compressors are provided with the appropriate equipment for pressure released starting. Compression generally takes place in two stages with intermediate cooling, with the final pressure being 30 bar.

The design must be matched to the total volume of the compressed air bottles connected to the system.

11.1.2 Compressed air bottles

The compressed air bottles are implemented as either vertically or horizontally installed vessels. The volume of the bottles is dependent on the type and number of engines connected and the required number of starts to be achieved without refilling the air bottles.

Compressed air bottles must be drained regularly. Vertical vessels can be drained via the valve head, horizontal vessels must be installed with a slope towards the base of the vessel, so that they can be properly drained through the base. Generally automatic drainage facilities must be provided. These must always be arranged beneath the vessel; the line from the vessel to the drain must always be laid with a continuous slope.

11.1.3 Compressed air pipes

An oil and water separator must be installed in the filling pipe between the compressor and the compressed air bottle if this is not provided on the compressor.

The starting pipe between the compressed air bottle (head of vessel) and the main starter valve must be as short as possible and must include the minimum number of elbows. Dependent on how the pipes are laid, an automatic drain facility must be fitted at the lowest points.

It is recommended that a dirt trap with drain-off valve be installed in the starter line. When fitting the dirt trap, pay attention to the orientation (sieve always to be removed from below) and the direction of flow. The dirt trap is a component of the start system for gensets with a compressed air starter.

In the case of multi-engine systems, a ring circuit may increase the starting availability of the system. Welding deposits and any other contamination must be avoided in the compressed air pipe.

The starting air pipes must always be stainless steel pipes (see also Chapter 20.2)!
11.2 Low-pressure air system

In the case of engine series TCG 2032, the pneumatic shut-off valves in the gas control line are supplied as standard with compressed air at max. 10 bar via a connection to the starter group. The low-pressure connection is not required if gas control lines are used with solenoid valves.

11.3 Safety Note

When carrying out work on the engine, it is essential to shut off the compressed air supply to the engine to prevent the engine from being started unintentionally.

11.4 Compressed air quality

The compressed air must be free from dust and oil. The compressors and air filters must be designed accordingly.
Power plants layout

Chapter 12

Measuring, monitoring and limiting devices

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12. Measuring, monitoring and limiting devices

12.1 Monitoring as per DIN EN 12828

12.2 Monitoring as per TRD 604

12.3 Temperature measurement

12.3.1 Installation note for temperature sensors

12.4 Differential pressure monitoring

12.5 Exhaust backpressure monitoring
12. Measuring, monitoring and limiting devices

These are used to protect and control the CHP module. Moreover, they are needed to fulfil the safety requirements for heat generators. Declarations of conformity and CE markings are necessary for the measuring, monitoring and limiting devices pursuant to the Low Voltage Directive 2014/35/EU and the Electromagnetic Compatibility Directive 2014/30/EU. The instructions for operation and use and the manufacturer's maintenance instructions must be taken into account when installing the measuring, monitoring and limiting devices.

When installing, it is essential to take account of the following:

- Permissible ambient temperature
- Permissible operating media
- Permissible operating media temperature
- Permissible operating pressure
- Permissible installation site
- Permissible flow speed
- Required minimum immersion depth
- Choice of cables as described in Chapter 17 (shielded sensor connection line)

12.1 Monitoring as per DIN EN 12828

In order to limit temperature, pressure, flow and low water level, the devices must fulfil the following requirements:

- Temperature sensors and limiters must be tested according to DIN EN 14597 (limiters with reactivation lock)
- Pressure limiters must be component-tested to VdTÜV Notice “Pressure 100/1” with reactivation lock
- Flow limiters must be component-tested to VdTÜV Notice “Flow 100”
- Water level limiters must be component-tested to VdTÜV Notice “Water level 100/2”

12.2 Monitoring as per TRD 604

In order to limit temperature, pressure and low water level, devices of a particular design must be used. Flow limiters must comply with VdTÜV Notice “Flow 100”.
12.3 Temperature measurement

Temperatures are detected with the aid of resistance thermometers in the water circuits and thermocouples in the exhaust. The temperature-dependent changes in resistance and thermoelectric voltage are converted via transmitters in the sensor head into a standardized 4 – 20 mA signal.

12.3.1 Installation note for temperature sensors

Fast measuring of dynamic temperature changes is an absolute requirement for a good control system. The installation position has a great influence on the response times and measuring errors. Figure 12.1 shows good and bad examples for installation in tubes. The length of the immersion sleeves has to be designed so that the sensor measures the temperature in the core of the flow. The sensor has to be connected to the immersion sleeve thermally by a conductive medium. Temperature-proof oils and heat-conductive pastes are suitable for this. Insulating air gaps between the immersion sleeve and sensor should be avoided in all cases.

Fig. 12.1 Installation of the temperature sensor

<table>
<thead>
<tr>
<th>bad</th>
<th>good</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Sensor not in the core of the flow)</td>
<td>(Sensor in the core of the flow)</td>
</tr>
</tbody>
</table>

1. PT 100 sensor
2. 4-20 mA transmitter
3. Immersion sleeve with air gap
4. Gap filled with thermally conductive medium

12.4 Differential pressure monitoring

Differential pressure switches are used to monitor differential pressures.
12.5 Exhaust backpressure monitoring

A special design of gas pressure monitor in the sense of VdTÜV Notice “Pressure 100/1” is used to monitor the exhaust backpressure. The measuring line must always slope upwards towards the sensor.
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Chapter 13

Mains connection conditions

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13.1.2 Dynamic network support ................................................................................................................... 3
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13. Mains connection conditions

Mains connection conditions regulate, among other things, the behavior of generating plants for electrical energy in the public electricity network under defined operating conditions. Mains connection conditions are specified by the relevant network operator with consideration of regulations coordinated in associations, national, European, or international committees corresponding to the needs of the mains in consideration.

13.1 Mains connection conditions in Germany: Generating plants’ connection to and parallel operation with the medium-voltage network

As a result of the progressing decentralization of power generation with photovoltaic, wind, water and CHP plants, these plants are becoming more and more significant within the mains power supply. In line with this, the connection conditions of power generators in the medium-voltage network have been revised in the following directive:

Generating plants connected to the medium-voltage network
Directive for generating plants’ connection to and parallel operation with the medium-voltage network
June 2008 version with the 4th amendment as of 2013-01-01

According to this new directive, CHP plants must also engage in the static and dynamic network support alongside the photovoltaic, wind, and hydroelectric systems.

13.1.1 Static voltage stability

Static voltage stability refers to voltage stability in the medium-voltage network for normal instances of operation. In this way, slow voltage changes in the distribution network are kept within contractual limits.

13.1.2 Dynamic network support

Dynamic network support is voltage stability when the voltage drops in the medium-voltage network. This prevents large feeder lines from disconnecting and the network from collapsing.
13.1.3 Requirements for the CHP genset

With the technical conditions for the static and dynamic network support described above, the requirements for the CHP genset (engine and generator) and for the operating mode of the plant have been changed. Before now, CHP plants were designed for maximum efficiency and maximum power at $\cos\phi=1$. With the new medium-voltage directive, other requirements have to be taken into account:

- Increased voltage and frequency range
- Reduced power over the frequency
- External power demand
- Variable $\cos\phi$
- Dynamic network support

For dynamic network support, the CHP plant must be able to remain above the characteristic line in the mains as specified in Fig. 13.1 in the event of a voltage drop and be able to ride through the following voltage characteristic line in the event of an FRT (Fault Ride Through).

**Fig.13.1: Borderline for the voltage profile at the mains connection point (in the event of an FRT)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Time of a fault occurrence</td>
</tr>
<tr>
<td>B</td>
<td>Lower value of the voltage band</td>
</tr>
<tr>
<td>t</td>
<td>Time in milliseconds</td>
</tr>
<tr>
<td>U/Uc</td>
<td>Ratio of actual mains voltage to agreed mains voltage</td>
</tr>
</tbody>
</table>
The agreed mains voltage $U_C$ is normally equal to the rated voltage $U_N$ of the mains.

The CHP plant may only be disconnected from the mains if the voltage at the mains connection point falls below the limit curve. If the voltage at the connection point falls below 30 % of the agreed mains voltage, the CHP plant can be disconnected from the mains. In the case of a voltage dip below 70 %, the disconnection may only occur after 150 ms.

The dynamic network support lays down high technical requirements for the CHP genset. The genset control and the components (e.g. moment of inertia of the generator) must be adapted for safe operation in the event of an FRT.

13.1.4 Certification of the gensets

The suitability of the generating plant for operation in the medium-voltage network must be validated and confirmed with a certificate by a certification body accredited according to DIN EN 45011.

The certifying body issues a type-specific GP certificate for the GP (generating unit). If the properties of the relevant protection device(s) are not identified in the GP certificate, the conformity validation can be realized by a component certificate of the relevant manufacturer, insofar as all framework conditions are fulfilled.

For the complete plant GP (generating plant), the certifying body issues a GP certificate and checks the correspondence between the plant actually installed and the properties specified in the GP certificate in a subsequent conformity declaration after commissioning.

Simulations for the FRT case are conducted with a calculation model as part of the GP certification for validation of the capacity for dynamic network support of the gensets. Commercial network calculation software is used for this. Worst-case conditions are assumed for these stability examinations, in order to simulate the critical cases that can occur in reality. The underlying calculation model was validated beforehand based on measuring results that were recorded during a type test for selected gensets: With the help of a test device designed for this, voltage dips according to Figure 15.1 are caused with defined residual voltage and specified duration. The representative electrical and mechanical variables occurring before, during, and after the fault are logged and are thus available for comparison with the results of a simulation of these tests.

13.2 International mains connection conditions

Along with the medium-voltage directive applicable in Germany, there are country-specific regulations which specify the framework conditions for parallel operation with the mains in other countries, both inside and outside of the EU. More and more countries are revising these regulations in consideration of the decentralized feeding and supply with renewable energy.
A comprehensive set of regulations for electricity grids in Europe has been drawn up by the European Network of Transmission System Operators for Electricity ENTSO-E. The framework conditions and limits for the country-specific directives/regulations are defined in the regulation Network Code for Requirements for Grid Connection Applicable to all Generators (NC RfG). Once the NC RfG is adopted, this regulation must be considered in the country-specific directives.

Furthermore, a standard for the mains connection conditions applicable in Europe is being prepared by CENELEC (European Committee for Electrotechnical Standardization). This standard will subsequently be published as a European standard.

Since the regulations in many countries are currently being revised or redeveloped, it must be checked for each genset/plant whether the conditions are observed.
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Chapter 14

Electrical switchgear systems

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14. Electrical switchgear systems

When equipping and installing switchgear systems, in addition to the generally acknowledged rules of engineering, particular attention should be paid to the following regulations:

- Low-voltage directive 2014/35/EC
- EMC Directive 2014/30/EU
- DIN EN 50156-1:2016-03
- VDE 0660-600-2 (DIN EN 61439-2, IEC 61493-2)
- If applicable, DIN EN 602014-1
- DGUV regulation 3, Electrical systems and equipment

When working in control / switch cabinets with electrical components, as well as handling electrostatically sensitive components (e.g. circuit boards), the service bulletin including the specially set out DIN EN 61340 – 5 – 1 has to be observed. The switchgear systems must be designed for ambient temperatures of 0 °C to 40 °C and for a relative humidity of 5-70 %.

An exception to this is the TEM control cabinets. Here, the internal temperature of the cabinet may rise to 45 °C.

If necessary, the lost heat of the switching device combinations has to be dissipated by means of thermostatic controlled fans in order to avoid excessive internal temperatures. Switchgear rooms must always be air-conditioned in order to keep the temperature and relative humidity at a constant level. Direct sunlight contact on the cabinets is to be avoided by means of an appropriate arrangement.

14.1 TEM system for gas engines

The TEM system is the brains of the entire gas engine module, including engine management, control and monitoring of the gas engine, and optionally also the emergency cooling, heating circuit control and monitoring. It is a user interface for operating and observing the system, it regulates and optimizes the combustion of gas in the cylinders, and it controls and monitors the engine/generator genset with all its auxiliary equipment. Through its monitoring functions, it protects the genset against impermissible boundary conditions and guarantees long service life. Thanks to the integrated regulatory functions, it ensures optimum, reproducible engine status values in all operating conditions.

The integral short- and long-term history stores the relevant measurement values on retentive data storage media and provides a transparent view of its own procedures.

14.1.1 TEM-EVO System

With the TEM-EVO System, the functions described in Chapter 14.1 are integrated in modular form.
In addition, by choosing from a wide range of options, the TEM-EVO System can be adapted to suit specific applications (e.g. anti-knock governor (AKR), engine room ventilation, control and regulation of the table coolers in the heating circuit, engine circuit, emergency cooling circuit and mixture cooling circuit as well as parameterizable measured values, counter values and control circuits, CH₄ value led operation etc.). The result is a simple-to-operate system with high operational reliability and optimized economic efficiency.

14.1.2 Layout

The TEM-EVO System comprises 3 components:

- Genset control cabinet (AGS) complete with connected cables to the genset; contains the genset control and the TÜV-tested safety chain. The length of cable between the gas engine and the TEM cabinet is 8 m (optionally 15 m).
- I/O-Controller for installation in auxiliary drives cabinet (HAS, max. 250 m distance from the genset control cabinet; cabling to comprise shielded 3-core bus line)
- Operating computer (max. 100 m distance from genset cabinet; cabling to comprise shielded 3-core line) for installation in the auxiliary drives cabinet or external control cabinet.

This layout minimizes the time it takes for cabling in the system.

The genset control cabinet is mounted in immediate proximity to the genset. Together with the factory-tested engine cabling, the cables fitted and tested on the genset control cabinet and connected to the genset (with plug connections on the genset end) ensure smooth commissioning and a high level of operational reliability. Signals relating to the power part are exchanged with the TEM-EVO System directly in the auxiliary drives cabinet via the I/O-Controller. Data is transmitted to the genset control via a fail-safe CAN bus connection.

The operating computer can be located on the system as desired, if required in the auxiliary drives cabinet or in the control room. The max. distance from the TEM cabinet is 100 m.

14.1.3 Operation log and histories

The recording functions of the electronic operating log kept by the TEM-EVO System take the place of a manual operation log. All operating messages and operationally relevant switching actions are recorded with a precise time stamp (date/time), as are all parameter changes.

As a whole, the TEM-EVO System can monitor and distinguish between over 600 different events. This makes it possible to provide fast and detailed analyses of genset operating modes, including TEM-EVO-controlled auxiliary functions.

The history function records up to 84 measured values. Up to 20 measured value curves can be jointly illustrated in one graph. The user can compile the measured value curves themselves.

TEM-EVO records histories at three speed stages:
• Working cycle history: records actual values in each operating cycle
  (1 operating cycle = 2 crankshaft revolutions)
• 6 min. history: records current values at one second intervals
• 40 h-history: records 6 min. measured values.

14.1.4 Diagnosis and service functions

In addition to the history and operation log, the basic TEM-EVO System also includes further diagnosis and
service functions which make a valuable contribution to the early detection of abnormalities and allow plant
system operation to be optimized. Fault situations are thus more quickly eliminated and also commissioning
becomes significantly simpler and faster. This contributes decisively towards the overall economic efficiency
of the gas engine set.

The following service and diagnostic functions are available:

• Auxiliary genset test mode
• Digital speed governor
• Electronic ignition system
• Parameterization
• Oil change
• Electronic operating hour meter
• Selection of language and printer
• System setup (software versions, serial numbers, color settings, screen saver, etc.)
• Other diagnostics/service masks for some options (e.g. anti-knock governor, dual gas operation)

The service and diagnosis masks, like all other masks, can also be accessed by analog modem via the
normal telephone network, IP modem via the internet, or radio modem for remote data transfer (optional). In
this way, remote diagnosis and remote repair can be provided with very short response times via our
Customer Service or the operator's own on-call staff.

14.1.5 Technical data

• Genset control cabinet: standard dimensions: 1200 x 800 x 300 mm (H x W x D); protection type:
  IP 54, operating temperatures: 5-45 °C, cables enter from below.
• I/O-Controller: dimensions: 114.5 x 112 mm (D x H); length dependent on number of options;
  protection type: IP 20, operating temperatures: 5-45 °C
• Operating computer: dimensions: 311 x 483 x 101 mm (H x W x D) including front plate; installation
depth 95 mm; cutout for mounting 282 x 454 mm (H x W) front-side protection type: IP 65, operating
temperatures: 5-40 °C
14.1.6 Installation notes for the I/O-Controller

The I/O-Controller must be installed in a horizontal 35 mm top-hat rail (DIN EN 60715) in a switch cabinet. The modules should be installed vertically (Figure 14.1), so that sufficient airing is guaranteed. The distance between two cable ducts should be 200 mm (minimum 160 mm). Space next to the IO modules is provided for possible retrofitting of other IO modules. This space may not be blocked by other components when installing the controller in the switch cabinet.

Fig. 14.1 I/O-Controller

<table>
<thead>
<tr>
<th>Item</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>red: bus coupler module COS</td>
</tr>
<tr>
<td>2</td>
<td>black: power module PM1S and PM2S, here PM2S</td>
</tr>
<tr>
<td>3</td>
<td>blue: I/O module DIM 8</td>
</tr>
<tr>
<td>4</td>
<td>blue: spare parts module DIM8</td>
</tr>
<tr>
<td>5</td>
<td>green: I/O module DOM8</td>
</tr>
<tr>
<td>6</td>
<td>green: spare parts module DOM8</td>
</tr>
<tr>
<td>7</td>
<td>yellow: I/O module AIM2</td>
</tr>
<tr>
<td>8</td>
<td>yellow: spare parts module AIM2</td>
</tr>
<tr>
<td>9</td>
<td>gray: I/O module AOM2</td>
</tr>
<tr>
<td>10</td>
<td>gray: spare parts module AOM2</td>
</tr>
</tbody>
</table>
14.2 Advantages for the user

TEM-EVO offers the user the following advantages:

- Compact structure and integration of numerous additional peripheral functions such as heat recovery, etc.
- High engine efficiency by controlled operation at optimum operating point.
- Permanently low exhaust emissions.
- High level of system reliability thanks to automatic plausibility checks.
- Rapid elimination of faults thanks to the display of measured values and warning and fault messages.
- Fast, cost-effective service thanks to extended diagnosis options backed up by short and long-term histories.
- Effective remote operation and remote diagnosis via the central control room or other external computer by telephone or radio modem (option).
- Additional remote diagnosis options from the Service via telephone modem (option).

14.3 TPEM system for gas engines

The TPEM system is the newly developed control and regulation system for operating an energy generation plant with gas engine gensets. TPEM is the abbreviation for Total Plant & Energy Management. Comprehensive monitoring functions protect the gas engine genset and the plant components associated with it from exceeding impermissible limits and thus guarantee ready availability and long service lives.
The TPEM system is structured in modules and can be flexibly adjusted to the local conditions.
The system is initially available for the series TCG 3016.

14.3.1 Design of the TPEM system

The TPEM system comprises the following main components:

- **TPEM Control Unit (TPEM CU)**
  The TPEM Control Unit includes the components of the TPEM system that are mounted on the gas engine genset. The interface to the TPEM control system forms the TPEM Connection Box also mounted on the genset. The cabling between the TPEM Connection Box and the TPEM control system is carried out by the customer as per the cable specification specified by CES. The maximum possible distance between the TPEM Connection Box and the TPEM control system is 100 meters.
- **TPEM Control Cabinet (TPEM CC)**
  The TPEM Control Cabinet is the control cabinet with hard-wired 15” touch panel for operation. It controls and regulates the gas engine, the generator and the auxiliary drives as well as the generator and mains circuit breaker. The interfaces for it are the TPEM I/O-Controller and the TPEM Multi Function Relay. The TPEM Control Cabinet still includes the TPEM Remote Plant Gateway for remote access and the safety chain certified by TÜV.

- **TPEM I/O-Controller (TPEM IO)**
  The TPEM I/O-Controller forms the interface between the TPEM system and the auxiliary drives. The I/O-Controller is installed in the auxiliary drives cabinet. The signals for controlling the auxiliary drives are supplied, the power supply for the auxiliary drives is to be provided separately. The distance between the TPEM Control Cabinet and I/O-Controller must not exceed 100 meters.

- **TPEM Rendezvous Server (TPEM RS)**
  The TPEM Rendezvous Server enables access to the TPEM system with a TPEM Remote Client via the internet.

- **TPEM Remote Client (TPEM RC)**
  The TPEM Remote Client is the piece of software used for visualization of the TPEM system on a computer. It differentiates between two access modes:
  a) for the CES service: remote diagnostics and remote maintenance of the plant
  b) for the operator: remote operation and remote monitoring of the plant

- **TPEM Token**
  The TPEM Token regulates authentication for local access and remote access to the TPEM system.

### 14.3.2 TPEM Functions

The TPEM system comprises all functions that are required to ensure a reliable, comfortable regulation and control of the gas engine genset and the plant associated with it. These functions are:

- Control of the actuators and signal analysis of the sensors on the TPEM I/O-Controller in the auxiliary drives cabinet; data transfer to/from the TPEM Control Cabinet.
- Test mode for verification of connected actuators, sensors and auxiliary drives
- Recording measured values (histories) for checking and diagnostic purposes
- Integrated data processing and monitoring of the sensors and actuators for electrical faults such as cable break and short-circuit
- Recording of alarms, warnings, operating messages and parameter changes with their dates and times of occurrence. The recordings are used for detailed monitoring of the operation
- Possibility for the connection of a service laptop to a service PC interface directly on the TPEM Control Cabinet
- Operator access to the TPEM control via Rendezvous Server and TPEM Remote Plant Gateway e.g. for remote diagnostics and/or remote maintenance and connection to a local network

Depending on plant-specific features, the TPEM system can be expanded and flexibly adjusted with special functions.

14.3.3 TPEM Control Cabinet

The Figure 14.4 shows the TPEM Control Cabinet. All the necessary terminal strips for connecting the TPEM CC are in the bottom of the switch cabinet. See area marked red in Fig. 14.4. Furthermore, the TPEM CC allows for cables to the connection terminal to enter from above. A pre-punched perforated plate is fitted in the ceiling of the switch cabinet, see upper blue arrow in Fig. 14.4. The cables connected from above are guided to the connection terminals in the lower part of the switch cabinet via the cable ducts installed on the side walls (blue markings in Fig. 14.4).
Fig. 14.4 TPEM Control Cabinet (TPEM CC)
14.3.3.1 TPEM MFR

The MFR (Multi Function Relay) contained in the TPEM Control Cabinet controls the generator circuit breaker and, when necessary, the mains circuit breaker. In each case, information on the status of the mains circuit breaker must be present for the MFR. Furthermore, the MFR supports the following generator and mains protection functions in accordance with the ANSI standard.

Table 1: Generator protection function

<table>
<thead>
<tr>
<th>Number as per ANSI/IEEE C37-2</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>81O/U</td>
<td>Overfrequency and underfrequency</td>
</tr>
<tr>
<td>59/27</td>
<td>Overvoltage and undervoltage</td>
</tr>
<tr>
<td>51V</td>
<td>Time-dependent overcurrent</td>
</tr>
<tr>
<td>50</td>
<td>Present overcurrent</td>
</tr>
<tr>
<td>46/47</td>
<td>Unbalanced load</td>
</tr>
<tr>
<td>32/32 R</td>
<td>Overload and reverse power</td>
</tr>
<tr>
<td>25</td>
<td>Synchronization check</td>
</tr>
</tbody>
</table>

Table 2: Mains protection function

<table>
<thead>
<tr>
<th>Number as per ANSI/IEEE C37-2</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>81O/U</td>
<td>Overfrequency and underfrequency</td>
</tr>
<tr>
<td>59/27</td>
<td>Overvoltage and undervoltage</td>
</tr>
<tr>
<td>78</td>
<td>Time-dependent overcurrent</td>
</tr>
<tr>
<td>25</td>
<td>Synchronization check</td>
</tr>
</tbody>
</table>

14.3.3.2 Notes on TPEM Control Cabinet

- The base of the TPEM Control Cabinet can be split up to reduce its height. This can produce base heights of 100 and 200 mm (see Fig. 14.4).
- It is recommended that the TPEM Control Cabinet be set up in an air-conditioned switchgear room.
- The maximum distance from the gas engine genset (TPEM Connection Box) is 100 meters.
- Pre-assembled cables with lengths of 25, 50, 75 and 100 meters are available as order options for connecting the TPEM Connection Box and the TPEM Control Cabinet. If necessary, a further adjustment of the length of the cables can be carried out. The cable specification is provided by CES.
14.3.4 Installation notes for the TPEM I/O-Controller

The I/O-Controller must be installed in a horizontal 35 mm top-hat rail (DIN EN 60715) in a switch cabinet. The modules should be installed vertically, see also Fig. 14.5. In order to guarantee sufficient airing, the distances as per Fig. 14.5 must be observed.

Fig. 14.5: TPEM I/O-Controller - Installation dimensions

14.3.5 Technical data

- TPEM Control Cabinet (TPEM CC)
  Dimensions: 2200/2100 x 800 x 600 mm (H x W x D)
  Protection type: IP 45
  Permissible operating temperature: 5 – 45 °C
  Cable inlet: alternatively from the bottom or from the top
14.3.6 Operation of the TPEM system

Easy operation of the TPEM system is ensured by an intelligent control computer with 15" a touch panel that can be used intuitively to access all functions.

The operator can use the navigation bar to quickly and directly change the mask displayed to operate the genset. Each operating mask informs the operator of the current status of the connected genset. All regulation, service, control and monitoring functions can be operated conveniently without a lengthy training period.

Communication with the user can take place in German, English and over 20 other system languages. The language can be changed at any time by pressing a button. Service work may be temporarily performed in a different language to that used by the site staff.

14.3.7 History

The operating history of the TPEM system ensures transparent operation of the gas engine genset, its peripheral components and the mains connection. All operating messages and operationally-relevant switching actions are recorded with a clear time stamp (date/time), as are all parameter changes.

As a whole, the TPEM system is able to monitor and distinguish between over 600 different events. This makes it possible to provide a fast and detailed analysis of the genset operation, including the TPEM-controlled auxiliary functions.

14.3.8 Histories

The histories function records all measured values. These can be displayed together in a single diagram when needed. The user can compile the measured value curves themselves.
14.3.9 Diagnosis and service functions

In addition to the history and operating messages, the TPEM system contains additional diagnostics and service functions that contribute significantly to the high availability of the gas-engine module. Commissioning also becomes easier and faster using these functions. Masks for service und diagnostics are available for:

- Auxiliaries test mode
- Electronic ignition system
- Parameterization
- Oil change
- Operating Hour Meter

14.4 Auxiliary drives control and supply – Auxiliary drives cabinet "HAS"

In addition to the TEM/TPEM system, a typical plant includes one cabinet for auxiliary drives, synchronization and generator protection for each genset, as well as the appropriate charging equipment. Auxiliary drives include all power supplies for pumps, control valves, flap valves, fans, etc. The synchronization function ensures synchronous connection to the mains by precision balancing. Control of engine speed is balanced to the mains frequency under consideration of voltage and phase relation. Generator protection covers all necessary and recommended monitoring facilities for generators as per ISO 8528 - 4.

The battery charging devices charge the battery during normal operation in accordance with the constant voltage/constant current curves.

14.5 Power part – Generator power field “GLF”

The power part includes the generator circuit breaker and the corresponding transformers to protect the generator. The current and voltage transformers are likewise located in the power part. In the case of voltages < 1 kV, the voltage is tapped directly from the rail.

With larger or medium-voltage systems, the power parts are installed in a separate switchgear room.
14.6 Central control - Central system control "ZAS"

The central control assumes all common control and monitoring functions which need to be taken into account with multi-engine systems. The ZAS includes:

- Integrated PLC (Programmable Logic Controller)
- Local operating level via touch panel

Functions of the central control for the individual gensets:

- Automatic/manual selection and deselection
- Specifying genset output
- Specifying operating mode (mains parallel, island or back-up mode)
- Mains consumption control
- Load share

Possible additional functions of the central control:

- Controlling the different operating modes
- Gas type selection
- Mains failure monitoring
- Controlling and monitoring the lube oil supply and used oil disposal (lube oil service tank, used oil tank)
- Controlling and supplying central pumps
- Controlling and supplying central emergency cooling facilities
- Monitoring and controlling a heat storage tank
- Gas tank level-dependent operation
- Controlling and supplying the ventilation system
- Controlling and supplying the gas warning system
- Controlling and supplying fire safety facilities, etc.

In addition, a manual operating level must also be provided to allow local control of the system in the event of a failure of the process management system.
Power plants layout

Chapter 15

Island mode

06-2017
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   / DIN VDE 0100-718 ..................................................................................................................... 8
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15. Island mode with gas engines

15.1 General description of island mode

On the electrical side, there are different possibilities for operating gas engines. In the majority of cases, the engines run parallel to the public mains. The public mains is viewed as a large system with very high inertia which will not drop or increase the level of voltage or frequency depending on the local load of the individual consumers. Gas engines are designed to operate parallel to the mains as described with optimized efficiency. But, in some cases, the customer has no or no continuous public mains access available. For this reason, island mode is available as an additional feature.

In island mode, it is not possible to control the power of the gas genset via the TEM/TPEM system. Thus, the power controller will be deactivated and the genset will be operated by speed regulation to maintain a constant frequency. In island mode, the TEM/TPEM system on its own can have no effect on the load of the genset. For this reason, the boundary conditions such as inlet air temperature and engine cooling water inlet must be followed. Therefore, the load switching to any gas genset - especially for the highly turbocharged gas gensets (TCG 2016, TCG 3016, TCG 2020, TCG 2032) - and the load shedding must be controlled by the customer's load management system. For this case, maximum permissible load steps for each gas genset were defined (see also Chapter 16, Load Steps).

For island mode with gas gensets, the whole system concept must be planned in detail from the beginning of the design process. Therefore, the system single line diagram and the knowledge of the customer's consumers (real starting power and start-up characteristic), especially for the large consumers like pumps and large fans, are important in order to achieve a good project status. Another important fact is to analyze the earthing concept for the whole system. In order to reach an effective integrated concept, coordination during project planning is offered to the customers.

Two possibilities of island mode are classified:

- Island mode after a changeover from mains parallel mode
- Island mode without a public mains access
15.2  Island mode after a changeover from mains parallel mode

In normal operation, the gas gensets run parallel to the public mains. Each genset is controlled by the power controller of the TEM/TPEM system. The frequency and voltage level of the gensets is set by the public mains.

In the case of a mains failure, the mains circuit breaker is opened immediately. The gas gensets will supply the consumers of the customer system without interruption.

The single line diagram (Fig 15.1) shows a typical layout for an emergency power supply. The gas engine auxiliary drives are supplied by an auxiliary transformer.

If there is a mains failure, the mains circuit breaker is opened and the gas genset will supply the consumers to the plant. Normally, the transition from mains parallel mode to island mode causes rapid load changing. If this load changing exceeds the relevant load steps, the turbocharger of the gas engine will start to pump and, in extreme cases, the gas engine will be switched off. A total power outage of the complete system may follow.

To solve this problem, various solutions are available which will be coordinated according to the requirements of the whole system during project planning. It is important to analyze the behavior of the gas engines together with the consumers to create an adequate concept.
Fig. 15.1 Island mode after a changeover from mains parallel mode
15.3 Island mode without public mains access

In island mode, it is important to analyze the start procedure and the load switching as well as the load shedding. In some cases, it is necessary to provide an emergency diesel or a UPS as auxiliary supply for prelubrication and after-cooling of the engine (see also Chapter 15.7, Black start).

The single line diagram (Fig.15.2) shows a typical layout for island mode. An emergency diesel genset is connected to the 400 V panel. The diesel starts at first and supplies the auxiliary panels. Then the first gas genset starts and supplies the customer's consumers and the auxiliaries as well via the auxiliary transformer. Now the diesel genset can be stopped.

If the operator wants to stop the whole system, all gas gensets except one are stopped subsequently and the stopped gas engines are cooled down. The diesel genset is now started and synchronized with the auxiliary busbar. After this, the breaker of the auxiliary transformer can be opened. The last gas genset can be stopped and cooled down. It is very important that the heat at the turbocharger is discharged after switching off each gas genset in order to protect it from overheating. When the after-cooling period has expired, the TEM/TPEM will stop the genset auxiliary drives and the diesel genset can be stopped as well.
Fig. 15.2 Island mode without public mains access
15.4 Back-up power operation according to DIN VDE 0100-710 / DIN VDE 0100-560 / DIN EN 50172 / DIN VDE 0100-718

For some special applications, it is necessary to supply power to important consumers for emergency reasons within 15 seconds. In order to realize this kind of emergency power supply, the function and load must be clearly defined in the project planning phase. The power available from the genset within 15 seconds corresponds to the first load step as per the load table (see also Chapter 16). For this application, the gas engine must be able to black start. This condition can only be fulfilled by single-engine systems of the series TCG 2016 C, TCG 3016 and TCG 2020 V12 and TCG 2020 V16. The TCG 2020 V20 is not suitable for back-up power operation because its startup time is too long.

In island mode with more than one gas genset, the first genset will supply the back-up power. The other gas gensets will start once the power supply of the first engine is stable. The auxiliary drive power for the other gas gensets will be supplied by the first one. The other engines will be synchronized to the first one. In some special cases, it is possible to start more than one gas genset to cover a higher amount of back-up supply as well. The available back-up power will be calculated according to the first load step multiplied by the number of running gensets. This is a very special application of the gas gensets and must be planned in detail.

Corresponding IEC standards:

- DIN VDE 0100-560 IEC 60364-5-56
- DIN VDE 0100-170 IEC 60364-7-710
- DIN VDE 0100-718 IEC 60364-7-718

15.5 Active load distribution in island mode

If more than one gas genset is running parallel in island mode, the load must be distributed between these gensets. Therefore, an active load balancer is integrated in the overall control system. The control system provides the following features: common frequency control for all synchronized gensets and optimized control signals to increase or decrease the power of each genset in order to avoid load oscillations between the gensets.

15.6 Starting of large consumers

Some consumers such as pumps or fans have an effective starting power, which is a multiple of the nominal power. In the case of a high effective starting power, it is necessary to use special starting procedures, for example, star / delta starting or soft starting. If there are consumers with a heavy starting torque, it is sometimes necessary to use load banks to start these large consumers. For this reason, it is necessary to check the customer system consumers and to coordinate the load switching during project planning.
15.7 Black start

If a gas genset is “black-started”, it starts without auxiliary drive power for prelubrication and cooling water pumps. The gas genset is started directly after the TEM/TPEM demand contact has been closed. The cooling water pumps start as soon as the auxiliary drive power supply is available. Furthermore, the gas genset will be started without prior leak monitoring of the gas control line.

The black start is an emergency function of the gas gensets and should be used only for emergency situations. Due to the high wear of the gas engine, this function should not be used more than three times a year.

The following gas engines are able to black-start:

- TCG 2016 V08 C / V12 C / V16 C
- TCG 3016 V08 / V12 / V16
- TCG 2020 V12 / V16 / V20
- TCG 2020 V12K / V16K

The black-start is purely a function for island mode and is not possible in mains parallel mode.

The TCG 2032 V12/V16 is not able to black-start. Because of the necessary prelubrication for this series before the engine starts, a power supply for the auxiliary drives is required, for example using an emergency diesel or UPS.

15.8 Minimum loads

In island mode in particular, the following restrictions for operating a gas engine genset with regards to the maximum availability and minimum maintenance cost must be observed.

Tab. 15.1 Restrictions for operation

<table>
<thead>
<tr>
<th>Power based on nominal load</th>
<th>Recommended maximum duration with this load</th>
<th>Recommended minimum duration in subsequent operation at load &gt; 50 % of the nominal load</th>
</tr>
</thead>
<tbody>
<tr>
<td>[%]</td>
<td>[Minutes]</td>
<td>[Minutes]</td>
</tr>
<tr>
<td>0 - 30</td>
<td>30</td>
<td>120</td>
</tr>
<tr>
<td>30 - 50</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>50 - 100</td>
<td>no restriction</td>
<td>No restriction</td>
</tr>
</tbody>
</table>
Fixed values for the genset power are still saved in the TEM/TPEM control system. The genset is switched off after a prior warning if the power falls below these fixed values.

### Tab. 15.2 Minimum loads

<table>
<thead>
<tr>
<th>Genset</th>
<th>Set minimum load [kW]</th>
<th>Warning when load falls below minimum after [Minutes]</th>
<th>Shutdown when load falls below minimum after [Minutes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCG 2016 V08 C</td>
<td>100</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 2016 V12 C</td>
<td>155</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 2016 V16 C</td>
<td>205</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 3016 V08</td>
<td>100</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 3016 V12</td>
<td>155</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 3016 V16</td>
<td>205</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 2020 V12</td>
<td>305</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 2020 V16</td>
<td>410</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 2020 V20</td>
<td>585</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 2032 V12</td>
<td>800</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 2032 V16</td>
<td>1060</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>TCG 2032B V16</td>
<td>1060</td>
<td>45</td>
<td>60</td>
</tr>
</tbody>
</table>

### 15.9 Earthing system

The earthing system for the system design must also be considered in good time; i.e. it must be studied according to the customer single line diagram of the whole system. Due to the complexity of some systems, the earthing concept must be adapted to the individual requirements. The genset manufacturer offers its customers coordination during project planning in order to develop an effective integrated concept.

### 15.10 Emissions

During island mode, the TEM/TPEM system regulates the exhaust gas emissions automatically. The typical value is 500 mg of NOₓ/Nm³ (in relation to 5% O₂, dry) or higher and can be parameterized by the commissioning staff. The higher enrichment of fuel / air ratio provides a better load changing behavior of the gas engine, but leads to a higher NOₓ level. If the emissions value must be smaller than 500 mg/Nm³ in island mode, the fuel / air ratio has to be leaner. In this case, the load step table (see Chapter 21) must be readjusted. The step levels must be decreased and, as a result, the number of step levels from idle to full load will increase.
15.11 Summary

To design a fault-free island mode operation, it is important to analyze the whole system and the customer's requirements during project planning. For this reason, it is necessary to check the following customer documents according to the requirements of the gas engine (for example load steps):

- Single line diagram of the whole system
- Actual starting power and starting conditions of large consumers
- Operating mode of the system
Power plants layout

Chapter 16

Load switching capability

06-2017
# Contents

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16.2 Variables influencing the load steps .................................................... 3
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16. **Load switching capability**

In the following tables and diagrams, the fundamental capability of load acceptance and load shedding is shown for a gas engine genset. The capability of load acceptance and load shedding depends on the engine specification, the gas engine's and generator's total moment of inertia and the plant conditions. The tables and diagrams that apply to the individual engine series are compiled in a separate bulletin. That is why this chapter is limited to a general description.

16.1 **Conditions for load switching**

In general, the following conditions apply to the load steps:

- Exhaust emission 500 mg NOx, or 5 % O₂ (stationary)
- Natural gas operation
- Warm engine
- ISO conditions
- Line from the zero-pressure controller of the gas control line to the gas mixer valve max. 1.5 m long
- Minimum gas pressure before the zero-pressure control line 100 mbar (note for plant design)
- Installation height < 500 m above sea level

The permissible load steps change in the case of deviating conditions.

When connecting electric drives (pumps, compressors) to the isolation busbar, it is necessary to consider their switching power in addition to their rated power.

16.2 **Variables influencing the load steps**

The following operating parameters influence the height of the load steps:

- air filter, clean / contaminated
- increased exhaust counter-pressure
- heat value of the combustion gas
- engine wear
- installation height
- air inlet temperature
- emissions values for NOx

Operation deviating from the design generally leads to a reduction in the permissible load step height.
16.3 Standards

The relevant standard for the load switching is DIN ISO 8528 Part 5. Various execution classes are defined in this internationally applicable standard, which describe the requirements for control accuracy in combustion engines.

There are three different classes: G1, G2 and G3.

With an increasing G-class, the requirements for the genset are raised, the tolerance bands become narrower and the required recovery times become shorter. With an increasing G-class, the permissible step height decreases with load switches for the same genset.

When planning a plant, it is therefore recommended to only choose the G-class which is really required for the respective application. The maximum step height can only be illustrated outside of the most roughly standardized accuracy class G1. Here it is only ensured that the engine is not damaged or goes into fault shutdown. The frequency drops or recovery times, however, are no longer defined.

The bulletin on load switching capability differentiates between two types of diagrams and tables. For each of the series TCG 2016, 2020 and 2032 there are diagrams for the maximum load steps without an allocation to one of the standardized accuracy classes. For the engine series TCG 3016 the diagrams and tables for the accuracy classes G1, G2 and G3 have been determined for the individual numbers of cylinders and speeds (50 Hz and 60 Hz).

16.4 Load steps in tables

The first column in the tables for the load application listed below shows how the engine can be loaded stepwise from zero load up to 100% load. The second column shows the recovery time that is required in order to get the frequency back into the tolerance band around the rated frequency after a load step. The third column shows the maximum speed drop expected when the specified steps are fully exhausted.

The tables for the load shedding show the stepwise load shedding from 100 % load to no-load. Load shedding from any load to 0 % or on auxiliary power in island mode is generally allowed, but should be avoided during normal operation. The genset is then protected.

Example: The gas engine genset illustrated in table 1 can be loaded with a maximum of 25 % in the first load step. Based on a preload of 25 %, this is a maximum of 17 % and with a preload of 42 %, it is a maximum of 13 %. The last load step is 7 % (from 93 % load to 100 % load). The same applies for load shedding. Only load shedding based on the current load can take place.
16.5 Load steps as diagrams

In the diagrams Fig. 1 and 2, the permitted load acceptance and/or load shedding of the engines is given as curves. On the x axis, you have the active load of the engines and the y axis shows the possible load application or the possible load shedding related to the active engine load. We will consider the example mentioned above once again. The diagram in Fig. 1 shows a falling curve in the engine loading range between 0 % and 55 % in the area of the load application. In this load range, the permitted load application decreases from 25 % to 10 % if the engine output is increased. In the load range from 55 % to 75 %, the permitted load application is 10 %. Above 75 % to 100 % the permitted load application continues to decrease. Upon reaching 100 % load, no additional load application is possible. Load shedding operates in the same way.
Load steps, without an accuracy class allocated

**Conditions**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
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<tbody>
<tr>
<td>Air intake temperature</td>
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</tr>
<tr>
<td>Intercooler inlet temperature</td>
<td>40 °C</td>
</tr>
</tbody>
</table>

**Moment of inertia of generator**

<table>
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<tr>
<th>Cylinder Number</th>
<th>Moment of Inertia</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>≥ XX kgm²</td>
</tr>
<tr>
<td>2</td>
<td>≥ YY kgm²</td>
</tr>
<tr>
<td>3</td>
<td>≥ ZZ kgm²</td>
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</tbody>
</table>

**Tab. 1 and 2 Load switching**

<table>
<thead>
<tr>
<th>Load application (Z)</th>
<th>PN [%]</th>
<th>t_{f,in} [s]</th>
<th>n [%]</th>
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</thead>
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<tr>
<td>0 - 25</td>
<td>15</td>
<td>-13</td>
<td></td>
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<tr>
<td>25 - 42</td>
<td>15</td>
<td>-11</td>
<td></td>
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<tr>
<td>42 - 55</td>
<td>15</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>55 - 65</td>
<td>15</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>65 - 75</td>
<td>12</td>
<td>-9</td>
<td></td>
</tr>
<tr>
<td>75 - 85</td>
<td>12</td>
<td>-9</td>
<td></td>
</tr>
<tr>
<td>85 - 93</td>
<td>10</td>
<td>-6</td>
<td></td>
</tr>
<tr>
<td>93 - 100</td>
<td>8</td>
<td>-6</td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load shedding (A)</th>
<th>PN [%]</th>
<th>t_{f,in} [s]</th>
<th>n [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 93</td>
<td>8</td>
<td>+6</td>
<td></td>
</tr>
<tr>
<td>93 - 85</td>
<td>10</td>
<td>+6</td>
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</tr>
<tr>
<td>85 - 75</td>
<td>12</td>
<td>+9</td>
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<tr>
<td>75 - 65</td>
<td>12</td>
<td>+9</td>
<td></td>
</tr>
<tr>
<td>65 - 55</td>
<td>15</td>
<td>+10</td>
<td></td>
</tr>
<tr>
<td>55 – 42</td>
<td>15</td>
<td>+10</td>
<td></td>
</tr>
<tr>
<td>42 – 25</td>
<td>15</td>
<td>+11</td>
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</tr>
<tr>
<td>25 - 0</td>
<td>15</td>
<td>+13</td>
<td></td>
</tr>
</tbody>
</table>

**Fig.1 Load switching**

**PN** Active load  
**t_{f,in}** Recovery time  
**LS** Load step  
**n** Speed change  
**Z** Load application  
**A** Load shedding
Load steps with accuracy classes according to DIN ISO 8528 Part 5

<table>
<thead>
<tr>
<th>Conditions</th>
<th>30 °C</th>
<th>≥ XX kgm²</th>
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</thead>
<tbody>
<tr>
<td>Air intake temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercooler inlet temperature</td>
<td>Natural gas 40 °C</td>
<td>Biogas 40 °C</td>
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</table>

**Tab. 3 and 4 Load switching, accuracy class G1**

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<tr>
<th>Load application G1</th>
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<th>Load shedding G1</th>
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<td>P_N [%]</td>
<td>t_f,in [s]</td>
<td>n [%]</td>
</tr>
<tr>
<td>0 - 27</td>
<td>15</td>
<td>-5.79</td>
</tr>
<tr>
<td>27 - 47</td>
<td>15</td>
<td>-6.61</td>
</tr>
<tr>
<td>47 - 65</td>
<td>15</td>
<td>-3.35</td>
</tr>
<tr>
<td>65 - 78</td>
<td>15</td>
<td>-5.90</td>
</tr>
<tr>
<td>78 - 90</td>
<td>15</td>
<td>-2.73</td>
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<tr>
<td>90 - 100</td>
<td>15</td>
<td>-3.40</td>
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</tbody>
</table>

**Tab. 5 and 6 Load switching, accuracy class G2**

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<tr>
<th>Load application G2</th>
<th></th>
<th>Load shedding G2</th>
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<td>P_N [%]</td>
<td>t_f,in [s]</td>
<td>n [%]</td>
</tr>
<tr>
<td>0 - 22</td>
<td>12</td>
<td>-3.03</td>
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<tr>
<td>22 - 42</td>
<td>12</td>
<td>-6.35</td>
</tr>
<tr>
<td>42 - 58</td>
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<td>-5.77</td>
</tr>
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<td>58 - 72</td>
<td>12</td>
<td>-1.91</td>
</tr>
<tr>
<td>72 - 84</td>
<td>12</td>
<td>-4.43</td>
</tr>
<tr>
<td>84 - 93</td>
<td>12</td>
<td>-2.73</td>
</tr>
<tr>
<td>93 - 100</td>
<td>12</td>
<td>-2.37</td>
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</table>

**Tab. 7 and 8 Load switching, accuracy class G3**

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<tr>
<th>Load application G3</th>
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<th>Load shedding G3</th>
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</thead>
<tbody>
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<td>P_N [%]</td>
<td>t_f,in [s]</td>
<td>n [%]</td>
</tr>
<tr>
<td>0 - 16</td>
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<td>-3.50</td>
</tr>
<tr>
<td>16 - 31</td>
<td>10</td>
<td>-2.39</td>
</tr>
<tr>
<td>31 - 46</td>
<td>10</td>
<td>-3.65</td>
</tr>
<tr>
<td>46 - 60</td>
<td>10</td>
<td>-3.99</td>
</tr>
<tr>
<td>60 - 72</td>
<td>10</td>
<td>-2.04</td>
</tr>
<tr>
<td>72 - 82</td>
<td>10</td>
<td>-2.36</td>
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<td>82 - 92</td>
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<tr>
<td>92 - 100</td>
<td>10</td>
<td>-2.95</td>
</tr>
</tbody>
</table>
Fig. 2 Load switching according to accuracy classes

<table>
<thead>
<tr>
<th>$P_N$</th>
<th>Active load</th>
<th>$t_{ijn}$</th>
<th>Recovery time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$LS$</td>
<td>Load step</td>
<td>$n$</td>
<td>Speed change</td>
</tr>
<tr>
<td>$Z$</td>
<td>Load application</td>
<td>$A$</td>
<td>Load shedding</td>
</tr>
<tr>
<td>$G$</td>
<td>Accuracy class according to DIN ISO 8058</td>
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Power plants layout

Chapter 17

Cabling

06-2017
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</tbody>
</table>
17. Cabling

The cabling for a CHP plant comprises power cables, supply lines for auxiliary drives, control cables and signal lines. Power cables, supply lines for auxiliary drives, control cables and signal lines must be laid separately.

It is essential to use flexible, oil-resistant, fine-wire control lines (e.g. H05VV5-F). Signal transmission lines must also be shielded (shielding to be composed of tinned copper braid with a minimum of 85 % coverage such as H05VVC4V5-K, not aluminum foil).

For the supply lines to the auxiliary drives, flexible, oil-resistant, fine-wire engine connection lines must be laid (e.g. H05VV5-F).

Cables for outside installation need to be suitable for installation in open air (weatherproof, UV-resistant, e.g ÖLFLEX Robust 215C).

The supply lines for frequency controlled drives need additional shielding (e.g. TOPFLEX EMV-UV-2YSLCYK-J). For frequency controlled drives, the total length of 100 m for the pipeline may not be exceeded. For the generator power cables, flexible multi-wire power cables (25 mm² upwards) made of copper must be used (e.g. NSGAFOU for low voltage and NTMCWOEU for medium voltage).

As protection against overload and short circuit, the lines must be fitted with line protection switches as per DIN VDE 0641 and/or DIN EN 60898; power switches as per DIN EN 60947-2 (IEC 60947-2) must be provided for the engines. The layout of the cabling should always be based on the currently applicable version of DIN VDE 0100. The cables must be routed through appropriate installation ducts and cable support systems. The cables must be laid in such a way as to prevent damage to the cable sheathing. This is of particular importance where cables are laid on a cable support system. That is, adequate edge protection must be provided. As a matter of principle, cables must be fixed / secured in such a manner as to prevent tension on the terminals (strain relief).

When laying cables, attention must be paid to measures designed to safeguard electromagnetic compatibility. (see Chapter 17.3).

Cable glands with integral strain relief must be used. The size must be selected to suit the external diameters of the cables.

When choosing and laying lines, the following points must be considered:

- Avoid possible mechanical or electrical interference between neighboring circuits.
- Consider the heat given off by lines and the chemical/physical effects of the line materials on adjacent materials such as e.g. structural or decorative materials, insulating conduits, fastenings.
- The heating effect of the current on the materials used for conductors, couplings and connections has to be considered as well.
A compilation of corresponding Standards and VDE Regulations is contained in Table 17.1.

Table 17.1
Extract from the respective standards:

**Power plants**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIN VDE 0100</td>
<td>Conditions for the erection of power installations with rated voltages up to 1000 V</td>
</tr>
<tr>
<td>DIN VDE 0100 Part 100</td>
<td>General requirements, scope</td>
</tr>
<tr>
<td>DIN VDE 0100 Part 410</td>
<td>Protective measures and protection against electric shock</td>
</tr>
<tr>
<td>DIN VDE 0100 Part 430</td>
<td>Protection of cables and lines against overcurrent</td>
</tr>
<tr>
<td>DIN VDE 0100 Part 482</td>
<td>Choice of protective measures, protection against fire</td>
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<tr>
<td>DIN VDE 0100 Part 520/Part 530</td>
<td>Erection of electric operating cables, lines and busbars</td>
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<tr>
<td>DIN VDE 0100 Part 520/Part 530</td>
<td>Erection of electrical operating material – switch and control devices</td>
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<td>Lights and lighting equipment</td>
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<td>DIN VDE 0100 Part 720</td>
<td>Industrial premises which are hazardous to fire</td>
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<td>DIN VDE 0100 Part 726 to Part 737</td>
<td>Hoists</td>
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<td>DIN VDE 0101</td>
<td>Erection of power installations with rated voltages above 1 kV</td>
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<td>DIN VDE 0105</td>
<td>Operation of power installations</td>
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<td>DIN VDE 0165</td>
<td>Erection of electrical equipment in hazardous areas</td>
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<tr>
<td>DIN VDE 0166</td>
<td>Electrical installations and apparatus thereof for use in atmospheres potentially endangered by explosive material</td>
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</tr>
<tr>
<td>DIN VDE 0185</td>
<td>Lightning protection systems, protection of structures against lightning</td>
</tr>
<tr>
<td>DIN VDE 0207 Part 1 to Part 24</td>
<td>Insulating and sheathing compounds for cables and insulated lines</td>
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<td>DIN VDE 0250 Part 1 to Part 819</td>
<td>Insulated power lines</td>
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<td>DIN VDE 0253</td>
<td>Insulated heating lines</td>
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Energy conductors

<table>
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<th>DIN VDE 0262</th>
<th>XLPE (cross linked PE) insulated and PVC sheathed installations cable up to 0.6/1 kV</th>
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<tbody>
<tr>
<td>DIN VDE 0265</td>
<td>Cables with plastic-insulated lead-sheath installations cable</td>
</tr>
<tr>
<td>DIN VDE 0271</td>
<td>PVC-insulated cables and sheathed power cables for rated voltages up to and including 3.6 / 6 (7.2) kV</td>
</tr>
<tr>
<td>DIN VDE 0276 Part 603</td>
<td>Power cables with rated voltages of 0.6/1 kV</td>
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<tr>
<td>DIN VDE 0276 Part 604</td>
<td>Power cables with rated voltages of 0.6/1 kV with special fire performance for use in power stations</td>
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<tr>
<td>DIN VDE 0276 Part 605</td>
<td>Additional test methods</td>
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<tr>
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<td>Distribution cables with rated voltages of 3.6 kV to 20.8/36 kV</td>
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<td>Halogen-free cables with improved characteristics in the case of fire; rated voltage from 6 to 30 kV</td>
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<td>Current carrying capacity, general; conversion factors</td>
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<td>PVC insulated power line</td>
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<td>Rubber-insulated electrical power lines: heat-resistant rubber and silicon single core, halogen-free single core, welding cable, rubber-insulated elevator control line, rubber hoses</td>
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<td>Mineral insulated lines of up to 750 V</td>
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<td>Definitions for power cables and insulated power lines.</td>
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<td>Code designation for harmonized cables and lines for power installations</td>
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<td>Core identification for power cables and insulated power lines of up to 1000 V</td>
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<td>Conductors for cables and insulated lines for power installations</td>
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<td>DIN VDE 0298 Part 1 to Part 300</td>
<td>Application of cables and insulated lines in power installations, recommended current load ratings</td>
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17.1 Safety requirements for the safe use of cables and lines

17.1.1 Fundamental requirements

When used in the manner intended, cables and lines should be regarded as safe; they present no unacceptable risk to life or property. Unless otherwise specified, insulated cables and lines must be used only to conduct and distribute electrical energy.

17.1.2 General Requirements

The lines selected must be adequate to accommodate the voltages and currents which may occur in all anticipated operating conditions in the operating equipment, system or components thereof in which they are used. They must be structured, laid, protected, deployed, and maintained in such a way as to avoid hazards as far as possible.

17.1.3 Cable design for normal operation

The conductor cross-section must be selected to ensure that, at the current load specified for the conductor, the permissible operating temperature is not exceeded at any time or at any point. The heating or the current carrying capacity of a cable or line is dependent on its structure, material characteristics and operating conditions.

The additional heating effect of heating ducts, solar radiation, etc. on bundled cables or lines should be considered and avoided. Where covers are used, it is important to ensure uninterrupted air circulation.
17.1.4 Operating mode

The mode of operation defines the time characteristic of the current. Continuous operation represents constant current operation, the duration of which is at least sufficient for the operating equipment to reach thermal steady-state, but is not otherwise limited in time. The design values for cables and lines are based on continuous operation, whereby the permissible operating temperature of the conductor is reached.

17.1.5 Ambient Conditions

Ambient conditions are marked by, among other things, the ambient temperature, heat loss and heat radiation. The ambient temperature is the temperature of the ambient air when the cable or line concerned is not under load. The reference temperature is +30 °C.

The operating conditions for cables and lines may vary both in the case of heat loss, for example in closed rooms, underfloor cable ducts, etc., and under the influence of radiated heat, e.g. the effects of the sun.

17.1.6 Conditions and requirements for permanently laid lines

Among others, the requirements for lines which are to be permanently laid are as follows:

- Lines must not come into contact with nor be laid in immediate proximity to hot surfaces, unless they are suited for it.
- Lines must not be laid directly in the soil.
- Lines must be secured in an appropriate manner. When selecting the distance between fixings, the weight of the line must be considered.
- The line must not be damaged by the mechanical means of fixing employed.
- Lines which have been in use for some time can be damaged if changes are made to the manner in which they are laid. This is due to the natural effect of aging on the physical characteristics of the materials used for insulating sleeves and sheathing. This process is accelerated by higher temperatures.

17.1.7 Requirements for flexible lines

- The length of connecting lines must be selected so as to be certain that the short-circuit protection devices will respond.
- The lines should not be subjected to excessive stresses due to strain, pressure, friction, twisting or kinking.
- Strain relief devices and connections must not be damaged.
- The lines must not be laid beneath covers or other operating equipment. There is a risk that they may suffer damage due to excessive heat build-up or mechanical damage due to being walked on.
The lines must not come into contact with nor be laid in the immediate proximity of hot surfaces.

The minimum bending radii must be observed.

### 17.2 Boundary conditions for the safe use of cables and lines

#### 17.2.1 Operating conditions

The lines selected must be suitable for the operating conditions and the respective protection class of the equipment concerned.

The operating conditions include, among others:

- Voltage
- Electricity
- Protective precautions
- Bundling of lines
- Type of laying
- Accessibility

The lines selected have to be suitable to withstand all external influences which may arise.

These external influences include, among others:

- Ambient temperature
- Rain
- Water vapor or accumulated water
- Presence of corrosive, pollutant or other chemical substances
- Mechanical stresses (e.g. sharp edges of metal structures)
- Animals (e.g. rodents)
- Plant life (e.g. mold fungus)
- Radiation (e.g. sunlight)

**Note:** In this context, it should be borne in mind that color is of great importance, and that the color "black" offers greater protection against solar radiation (high resistance to UV radiation) than other colors.

#### 17.2.2 Voltage

The nominal voltage of a line is the voltage for which the line is designed and which is used as a definition for electrical tests. The nominal voltage is specified in Volts using two values $U_o/U$ where: $U_o$ is the r.m.s. value of the voltage between an external conductor and earth (metal sleeves of the line or surrounding medium). $U$ is the r.m.s. value of the voltage between two external conductors of a multi-core line or a
system of single-core lines. In an AC voltage system, the nominal voltage of a line must at least correspond to the $U_o$ and $U$ values of the system.

17.2.3 Current carrying capacity

The nominal cross-section of a conductor should be selected so that its current carrying capacity is not less than the maximum continuous current flowing through the conductor under normal conditions. The limit temperatures to which the current carrying capacity relates must not be exceeded either for the insulating sleeve or sheathing of the respective line type. Among the defined conditions is also the manner in which the line is laid. Attention should be paid here to the specified permissible current loads.

The conditions to be taken into account include, among others:

- Ambient temperature
- Bundling of lines
- Type of overcurrent protection
- Heat insulation
- Rolled or coiled lines (should be avoided)
- Frequency of the current (in deviation from 50 Hz)
- Effects of harmonics.

The conductor cross-section should not be selected simply in accordance with the requisite current carrying capacity (DIN VDE 0298-4). Rather, the requirements for protection against hazardous shock currents, overload and short-circuit currents and voltage drop should be considered. If lines are operated for extended periods at temperatures higher than those specified, they may suffer serious damage which can lead to premature failure, to a significant impairment of their characteristics and life threatening situations.

17.2.4 Thermal Influences

Lines should be selected, laid and installed so as to ensure that the anticipated release of current-induced heat is not obstructed and there is no risk of adjacent materials catching fire. The limit temperatures for the individual line types are specified by the manufacturer. The specified values must, under no circumstances, be exceeded due to the interaction between internal current-induced heat and ambient conditions. The typical temperature range for permanently laid standard cables is -40 °C to +80 °C. If higher temperatures occur, heat-resistant cables must be used.

17.2.5 Mechanical influences

When assessing the risks of mechanical damage to the lines, consideration must be given to all mechanical stresses which might arise:
17.2.5.1 Tensile load

The strain values specified for the cables must not be exceeded. Typical values are 50 N/mm² for permanently installed lines and 15 N/mm² for flexible lines. In cases in which the above-mentioned values are exceeded, it is recommended that a separate strain relief element or similar be fitted. Such strain relief elements should be connected to the line in such a way that they do not damage the line.

17.2.5.2 Bending stresses

The internal bending radius of a line should be selected in order to avoid damage to the line. The internal bending radii for the different types of control lines are approx. 10 x line diameter (dependent on cable type and manufacturer) and for power cables approx. 15 x cable diameter or 5 – 10 x cable diameter for flexible lines. The minimum bending radius must in each case be checked for the particular lines/cables used. When stripping the insulation, care must be taken not to damage the conductors, as otherwise their bending behavior will be seriously impaired.

The specified bending radii apply at ambient temperatures of 20 °C (±10 K). For other ambient temperatures, account must be taken of the manufacturer's specifications.

Bends should be avoided in the immediate vicinity of external or internal fixing points.

17.2.5.3 Pressure load

Lines should not be subjected to such pressure as might damage them.

17.2.5.4 Torsional stresses

Flexible lines are generally not intended to support torsional stresses. Where such torsional stresses are unavoidable, this must be clarified on a case-by-case basis with the cable manufacturer.

17.2.6 Room types

Electrical operating premises are rooms or locations used primarily for the operation of electrical equipment and generally accessible only to trained personnel, e.g. switch rooms.

Sealed electrical operating premises are rooms or locations used exclusively for the operation of electrical equipment and kept under lock and key. Access is permitted only to trained personnel, e.g. sealed switching and distribution systems.

Dry rooms are rooms or locations which are generally devoid of condensation, or in which the air is not saturated with moisture.

Damp and wet rooms are rooms or locations in which the safety and reliability of the operating equipment is impaired by moisture, condensation, chemical or similar influences.
General notes:
To assign rooms to one of the above listed types often requires a precise knowledge of local and operational conditions. If for example a high level of moisture occurs only at one specific point in a room, but the room itself remains dry thanks to regular ventilation, it is not necessary to classify the whole room as a wet room. Since in CHP plants it is impossible to exclude oil and water leaks, oil and chemical-resistant cables must be used.

17.2.7 Types of use and stresses

Electrical lines may be divided between the following types of use:

- Cables for use in interior rooms, e.g. CHP room
- Cables for use in the open air, e.g. supply line for dry coolers

17.2.8 Subdivision of stresses

The term "stress" defines the suitability of a line for use in certain areas, on or in an item of operating equipment, and for certain combinations of external influences which occur in these areas.

In terms of stresses, electrical lines are divided into four categories:

- Very low stress, e.g. computer systems
- Low stress, e.g. air conditioning, data processing
- Normal stress, e.g. mechanical engineering, CHP, system manufacturing
- Heavy stress, e.g. mining

17.2.8.1 Use in interior rooms

The line is installed or connected to a piece of equipment which is permanently located inside a building, namely within the "specified environment". The building may be used for commercial, industrial or residential purposes.

17.2.8.2 Permanent open-air use

The line is designed to resist the widely varying stresses which may occur in the "specified environment", namely the open air (including the effects of weather).

17.3 Measurement to safeguard EMC

The line arrangement contributes to an essential part of the EMC of a system. The lines have to be graded in four groups:

- Group I: Very interference-susceptible (analog signals, measuring lines)
- Group III: Interference-susceptible (digital signals, sensor cables, 24 VDC switch signals)
- Group III: Fault source (control cables for inductive loads, unswitched power cables)
- Group IV: Strong fault source (output cables of frequency converters, switched power cables)

Crossing should be avoided when arranging the cables. If there are unavoidable crossings, the lines of the different groups must cross at right angles.

17.3.1 EMC instructions for use of frequency converters

Depending on the EMC requirement (environmental class 1 or 2) and type of frequency converter, EMC filters are required. Attention must be paid to the cabling and EMC instructions in the operating manual.

17.3.2 Cable ducts

- Metallic cable ducts have to be connected to the ground (earthing). They must be connected constantly
- Reduction of the magnetic field through distance of the cable troughs (Fig.17.1)
- Lines are installed in various cable ducts
- Lines separated through metallic partition
The recommended minimum distance between cable troughs is 0.15 m. The troughs should be electrically connected to the vertical carriers. The cable duct for the signal transmission lines should be covered.

In general, the power cables of generators should be laid separately. In the case of power cables, it must be noted that the type of routing has a significant influence on the current carrying capacity of the line. The correction factors in the standards must be observed here. The standard VDE 0298 specifies a distance of 0.3 meters between the cable conductors and to the ceiling when routing cables on cable conductors. See also 17.4.

17.3.3 Cable fittings

In the case of particular EMC requirements, EMC-type cable fittings should be used. In general, chromed brass fittings are used. Paragraph 17.4.4 is to be observed in respect to screw connections for generator power cables.

17.4 Generator power cables

The standards and directives applicable at the installation site must always be observed for the layout and routing of generator cables. The cable layout based on the German regulations is described in the following sections.
### 17.4.1 Cable layout

The standard DIN VDE 0298-4: 2013-06 (IEC 60364-5-52) is applied as a basis for calculating the number and cross sections of the cables. The following points are to be observed for the calculation:

- Ambient temperature
- Load bearing capacity (three-phase or single-phase)
- Type of laying

These criteria will be dealt with in more detail below. Various correction factors, which affect the current carrying capacity of the cable, are defined for each of these points.

#### 17.4.1.1 Ambient temperature

The ambient temperature has an effect on the current carrying capacity of the power cable. A relatively high temperature results in the genset room due to the heat dissipated from the engine. Therefore the cable types used should exhibit a permissible operating temperature at the conductor of minimum 90 °C.

The cable NSGAFÖU is recommended for low-voltage applications and the cable NTMCWOEU is recommended for medium voltage. These cables are used in the switch cabinets of Caterpillar Energy Solutions, the following calculations referring to their properties. Other cable types can also be used. It must be ensured that these involve flexible cables, as only limited space is available in the generator connection boxes. It is also necessary to check whether the cables can be used at the installation (for example USA and Canada require special cables).

The correction factors for divergent ambient temperatures from Table 17.1 of the standard VDE 0298-4 apply for the above cables.

<table>
<thead>
<tr>
<th>Ambient temperature in °C</th>
<th>Correction factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1.00</td>
</tr>
<tr>
<td>35</td>
<td>0.96</td>
</tr>
<tr>
<td>40</td>
<td>0.91</td>
</tr>
<tr>
<td>45</td>
<td>0.87</td>
</tr>
<tr>
<td>50</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Table 17.2 Extract from VDE 0298-4 Table 17
17.4.1.2 Cluster / Laying

The load bearing capacity of the cables also depends on whether direct, alternating or three-phase current circuits are involved. The correction factors for the various loads depend, in turn, on the laying. As the generating plants of Caterpillar Energy Solutions always feed into a three-phase current network, only the corresponding correction factors are considered at this point. When laying bundled or touching lines, the following values are defined in the standard VDE 0298-4 (Table 14):

- Laying on surfaces (for example: floor, wall): 0.67
- Laying free in the air (for example: cable conductors): 0.7
- Laying in tubes / ducts: 0.54

In addition to this factor, a correction factor for the special laying type must be considered. It must be ensured during the laying that the heat resulting due to the load on the cables can be dissipated. Various factors play a role here, for example the substrate, the spacing between the cables themselves as well as the distance to the surrounding parts.

When using a cable conductor where the cables are surrounded by air on all sides, the heat can be dissipated significantly better than, for example, on a cable trough. The containers of Caterpillar Energy Solutions are therefore designed with cable conductors as standard.

The correction factors for laying on cable conductors and cable troughs can be found in Table 23 of the standard (VDE 0298-4). The cables are laid in bundles of three in this table (Fig. 17.2). For the standard containers of Caterpillar Energy Solutions, the laying can be realized according to Fig. 17.3 owing to continuous ventilation and accumulated heat thereby avoided. This laying can also be used for draft-ventilated genset rooms in compliance with the ambient conditions. Of course, cables can also be laid individually with spacing between them, resulting in a correspondingly large space requirement (Fig. 17.4). The correction factors in the standard must be observed for other types of laying.

Fig.17.2 Laying in bundles of three
In order to keep the correction factors as low as possible, laying on a cable conductor is recommended, on which all power cables are arranged horizontally in groups of four. If several cable conductors/cable troughs have to be laid over one another for space-related reasons, the correction factors in Table 23 of the standard apply. The cable conductors must have a minimum distance of 300 mm from the ceiling and between one another.

The correction factors for laying according to Fig. 17.2 on cable troughs and cable conductors are shown below. Comparison of these values reveals that a laying on cable conductors exhibits the more favorable correction factors, as the heat is dissipated better there. It also becomes clear that the laying on a conductor does not result in any reduction of the current carrying capacity of the cable, as the correction factor 1.0 is used here. This also applies if the number of three-pole current circuits is greater than 3. According to this, a correction factor with 1.0 can be assumed in case of eight cables per phase on a cable conductor, as long as the specified distances are observed. The same applies for laying according to Fig. 17.3 in draft-ventilated rooms.
Table 17.3: Extract from VDE 0298-4 Table 23, Correction factors

<table>
<thead>
<tr>
<th>Perforated cable troughs</th>
<th>Number of troughs</th>
<th>Number of three-pole current circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>1.00</td>
<td>0.98</td>
</tr>
<tr>
<td>2</td>
<td>0.97</td>
<td>0.93</td>
</tr>
<tr>
<td>3</td>
<td>0.96</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Table 17.4: Extract from VDE 0298-4 Table 23, Correction factors

<table>
<thead>
<tr>
<th>Cable conductor / Cable tray</th>
<th>Number of trays</th>
<th>Number of three-pole current circuits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>2</td>
<td>0.97</td>
<td>0.95</td>
</tr>
<tr>
<td>3</td>
<td>0.96</td>
<td>0.94</td>
</tr>
</tbody>
</table>

17.4.2 N-conductor

According to the current guideline, the N-conductor can be designed half cross section, given that the harmonic content in the current is less than 10 %. As the harmonic currents depend on the load, in other words the consumers, these vary specific to the plant. The N-conductor is therefore listed with complete cross section in the overview table in Chapter 17.4.7.

17.4.3 Short-circuit-proof laying

In the event of a short-circuit, enormous forces result, which can cause the power cables to move considerably. In order to prevent damage to the insulation of the cables or to surrounding parts, a short-circuit-proof laying must be ensured. The cable bundles are wrapped with five wraps of cable bundle tape every 0.5 – 1 m for this. To prevent the cable bundles from moving, they are fastened on the cable conductor with a cable clip every 2 m. The minimum bending radii of the cables used must be observed for the laying. Failure to comply can result in damage to the insulation.

17.4.4 Screw connections

Screw connections with integrated strain relief must be used for introducing the power cables in the generator terminal boxes. These prevent forces from acting on the connecting terminals in the generator. In addition, the screw connections should not exhibit any edges where the cable chafes, thereby damaging the insulation. Here the recommendation on the part of CAT ES is to use so-called bell-mouth screw connections (Fig. 17.5).
17.4.5 Cable outlet

The cable outlet can be realized on both sides (right or left) upwards or downwards out of the generators. The low-voltage generators are connected upwards and the medium-voltage generators are connected downwards as standard.

The cables must be held with a suitable device relatively soon after the outlet from the generator (see Figures). The cables must be fastened with cable clamps. Fastening with cable ties is not permissible as this results in damage to the insulation. It must also be ensured that the cables are not laid with tension but instead provided with a curvature, which prevents the genset from vibrating.

Fig. 17.4.5 Low-voltage connection  Abb. 17.4.6 Medium-voltage connection
17.4.6 Example calculation for the cable layout

This section describes the cable calculation taking as an example the TCG 2020 V12 with 400 V +10 %, 50 Hz.

**Cable type:** The calculation is made with the cable NSGAFÖU with a cross section of 300 mm². The current carrying capacity is 898 A for an individually laid line. The data is taken from the data sheet or the valid standard of the corresponding cable type.

**Temperature:** As the cable layout is also valid for the standard MWM ES containers, and these reach up to 45 °C in summer, this temperature is assumed as the basis for the calculation. This results in a correction factor of 0.87 (Table 17.2).

**Laying:** The low-voltage power cables are laid in the four-set bundle on cable conductors as standard in the containers, which means we continue in this example with the factor 0.7 for the laying of bundled lines in air. As all cables are laid on a cable conductor and the containers are draft ventilated, the factor 1.0 can be used from Table 17.4.

**Result:** Applying the above correction factors yields a current carrying capacity per cable of:

\[
I = \frac{P}{\cos \phi \cdot \sqrt{3} \cdot 0.9 \cdot U_N}
\]

\[
I = \frac{1200 \text{ kW}}{0.8 \cdot \sqrt{3} \cdot 0.9 \cdot 400 \text{ V}} = 2406 \text{ A}
\]

The number of cables used per phase is then calculated from the maximum current and the current carrying capacity of the cable.

\[
2406 \text{ A} / 547 \text{ A} = 4.4 -> 5 \text{ cables per phase}
\]
This calculation basis can be adapted to all genset combinations. At this point, however, it must be pointed out again that the regulations and specifications valid at the installation site must always be observed. Moreover, other correction factors may be valid for other cable types.

### 17.4.7 Overview of the cable layout

Table 17.5 shows an overview of the recommended cable cross sections for the 400 V gensets. It must be noted that these cross sections are only valid for the ambient conditions indicated. Tables for other voltages are available on request.

**Table 17.5 Cable layout for voltage 400 V, cable type NSGAFÖU, environment 45 °C**

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Genset</td>
<td>Generator</td>
<td>Power</td>
<td>Maximum operating current</td>
<td>Number of cables (per phase)</td>
<td>Number of cables (N-conductor) *</td>
<td>Total number of cables</td>
<td>Cross section</td>
</tr>
<tr>
<td>TCG 2016/3016 V08 C</td>
<td>MJB 355 MB4</td>
<td>400</td>
<td>802</td>
<td>2</td>
<td>2</td>
<td>8</td>
<td>240</td>
<td>M 50</td>
</tr>
<tr>
<td>TCG 2016/3016 V12 C</td>
<td>MJB 400 LC4</td>
<td>600</td>
<td>1203</td>
<td>3</td>
<td>3</td>
<td>12</td>
<td>240</td>
<td>M 50</td>
</tr>
<tr>
<td>TCG 2016/3016 V16 C</td>
<td>MJB 450 MB4</td>
<td>800</td>
<td>1604</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>240</td>
<td>M 50</td>
</tr>
<tr>
<td>TCG 2020 V12K1</td>
<td>MJB 450 LB4</td>
<td>1000</td>
<td>2005</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>300</td>
<td>M 63</td>
</tr>
<tr>
<td>TCG 2020 V12K</td>
<td>MJB 500 MB4</td>
<td>1125</td>
<td>2255</td>
<td>5</td>
<td>5</td>
<td>20</td>
<td>300</td>
<td>M 63</td>
</tr>
<tr>
<td>TCG 2020 V12 (1 MW)</td>
<td>MJB 450 LB4</td>
<td>1000</td>
<td>2005</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>300</td>
<td>M 63</td>
</tr>
<tr>
<td>TCG 2020 V12</td>
<td>MJB 500 MB4</td>
<td>1200</td>
<td>2406</td>
<td>5</td>
<td>5</td>
<td>20</td>
<td>300</td>
<td>M 63</td>
</tr>
<tr>
<td>TCG 2020 V16K</td>
<td>MJB 500 LA4</td>
<td>1500</td>
<td>3007</td>
<td>7</td>
<td>7</td>
<td>28</td>
<td>300</td>
<td>M 63</td>
</tr>
<tr>
<td>TCG 2020 V16</td>
<td>MJB 500 LA4</td>
<td>1560</td>
<td>3127</td>
<td>7</td>
<td>7</td>
<td>28</td>
<td>300</td>
<td>M 63</td>
</tr>
<tr>
<td>TCG 2020 V20</td>
<td>MJB 560 LB4</td>
<td>2000</td>
<td>4009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend for column headings**

- **A**: Genset
- **B**: Generator
- **C**: Power
- **D**: Maximum operating current
- **E**: Number of cables (per phase)
- **F**: Number of cables (N-conductor) *
- **G**: Total number of cables
- **H**: Cross section
- **I**: Screw connection

Copper rail system
Type of laying

Validity:

- The layout shown in Table 17.5 applies to forced-ventilation genset rooms in compliance with the indicated ambient temperature and layout type.
- The layout applies for voltages 400 V ±10 % and 415 V ±10 %, 50 Hz

Laying conditions:

- Laying of the cables on cable conductors according to above diagram.
- Spacing of the cable conductors up to ceiling ≥300 mm.
- The cable bundles must be wrapped every 0.5 m with five wraps and fixed every 2 m with cable clamps on the cable conductor.
- The control cables must be routed on a separate cable rack/cable trough.
- The laying conditions must be strictly observed, as otherwise an overloading of the individual wires and resultant fires can occur.

Note *: The number of cables of the N-conductor can be reduced to half if the content of harmonic currents is less than 10 %.
17.5 Examples for cable arrangements

Fig.17.8
Shows a starter cable arrangement. The cables are laid symmetrically and secured with cable clamps. This prevents damage due to abrasion.

correct
Fig.17.9
Shows a starter cable which is installed incorrectly.
Abrasion danger!
Possible short-circuit danger!!
Fig. 17.10

Shows the arrangement of temperature sensor and fan motor cables.

The power supply cables are connected to the equipment in an installation system. The cables should be connected to the equipment from below. It must be ensured that the cable entry point is properly sealed.

correct
**Fig. 17.11**

Shows an incorrect cable installation. Rolling up the cables as a coil at the engine is not permitted because of additional load of the plugs and EMC problems.

Abrasion danger! EMC problems!

incorrect
Fig.17.12
Shows the vertical arrangement of engine cables up to a cable trough at ceiling height. The access point into the cable trough is fitted with the necessary edge protection and the cables are secured with cable clamps (do not use cable ties)
The line to the gas mixer regulating valve is poorly laid and therefore constitutes a negative example. The cable should not be fixed directly to a pipe (danger of abrasion) and it must not be rolled up in a coil (faults, mechanical wear).

correct

incorrect
Fig. 17.13
This picture shows a cable, which is laid loose and directly on the engine and the generator. Cable damages and EMC problems are the result of this.
Abrasion danger! Danger of short circuit! EMC problems!

incorrect
Fig. 17.14
Shows the equipotential bonding for the cooling water pipe across the rubber expansion joint. The cable is too long and is resting against the exhaust line insulation.
Abrasion danger! Impermissible heating!

incorrect
**Fig. 17.15**
The shield is too long, stripped and not laid separately on the terminal. The wires are laid on the terminals as long loops. This causes the risk of EMC problems and short-circuits.
EMC problems! Danger of short circuit!

**incorrect**
Fig. 17.16
In the following picture, the shielding is too long and not insulated. The wire terminal sleeves are missing on the external black cables.
Danger of short circuit!

incorrect
Fig. 17.17
Shows an arrangement of TEM cables running to the genset. These are fed to the engine in cable troughs. The power cables are secured after the 90° bend in order to prevent abrasion and to ensure the appropriate strain relief.
The 90° bend in the power cables absorbs vibrations which thus do not place strain upon the cable fittings at the connections.

**correct**
Fig.17.18
Shows correctly laid cables with clamps and cable ducts.
Fig.17.19
Shows correctly laid cables with clamps and cable ducts.

correct
Fig. 17.20
Shows a TEM cabinet, which is standing directly in front of the generator’s exhaust air. This causes the TEM cabinet to overheat. The temperature inside the cabinet is therefore too high and this is what causes the problems.
Temperature problems!

incorrect
Fig. 17.21
It is impermissible to close or to cover the air ducts.
Heat accumulation!

incorrect
Fig. 17.22
The power cables should be connected to the generator professionally.
Danger to life! Danger of short-circuit! Danger of fire!

incorrect
Fig. 17.23
The cable entrance is covered with sheet metal, so that no object can fall into the opening and cause a short-circuit.

correct
Fig. 17.24
The requested bending radii for the generator power cables are observed and the weight of the cables is borne by the fixed supports.

correct
Fig.17.25
The required bending radii of the generator power cables are observed, but the weight of the cables affects the screw connections and terminals. This arrangement is not short-circuit-proof.

incorrect
Fig. 17.26

The bending radii for the generator power cables are too narrow. The cables partly chafe the union nuts of the cable glands.

incorrect
Fig.17.27
It is not permissible to lead the power cables through the control cabinets and TEM cabinet.
EMC problems!

Incorrect
Power plants layout

Chapter 18

Transport and positioning of gensets

06-2017
18. Transport and positioning of gensets

18.1 Preliminary notes

The transport of a genset from the factory to its final destination can be divided into the following steps:

- Loading of the genset onto truck by stationary crane or mobile crane
- Transport by truck to destination or to harbor for shipping
- Reloading in harbor or when changing truck
- Unloading at destination by mobile crane or permanently installed crane
- Positioning and placement on the foundation

18.2 Loading by crane

The loading of gensets in the factory is done using either an in-door crane or a mobile crane. The gensets are either equipped with load support points (bollards) which are arranged on each side of the genset's base frame or in special cases by two double-T members which are arranged below the base frame. Those double-T members are equipped with shackles for fixing the lifting devices (ropes or chains). The location of the load support points is arranged symmetrically to the genset's center of gravity, so that the genset is suspended in a stable horizontal position during lifting when using four ropes or chains of equal length.

One end of the chains or ropes must be hooked to the crane's hook or to a traverse. The opposite ends have to be fastened to the load support points of the genset. The fastening must be secured against unexpected sudden loading.

For this reason, chains and ropes must only be secured using either clamps (lifting clamps) or textile slings when fastening them onto the transport brackets of the genset.

When arranging chains or ropes for lifting a genset, it must be ensured that the chains or ropes are only touching the genset at the load support points, thus preventing damage to genset components due to slanting chains or ropes. This prevents e.g. genset components from becoming damaged by the presence of sloping ropes or chains. Corresponding traverses are used for this, see Figure 18.1. If appropriate traverses are absent, straddling devices must be attached at the ropes or chains.
18.2.1 Load support equipment/hoists

Load support equipment, hoists and fastening equipment which are used for lifting and transporting heavy loads are subjected to special monitoring and test procedures both when this equipment is produced and during its operation life. In the European Union, the rules according to Classification as per German Health and Safety at Work Regulations (BetrSichV) and the rules of the Employers’ liability insurance association (DGUV=German Statutory Accident Assurance) must be observed. The main items to be observed are listed in the following.

- Only trained persons may use the lifting and transport equipment.
- The permissible load may not be exceeded on any equipment.

Before using any of this equipment, it has to be checked for proper condition, i.e. it must not show any damage affecting its safety and function (for example breaks, chamfers, cracks, cuts, wear, deformations, damages caused by exposure to heat or cold, etc.).
The equipment must not be overloaded with joints.
There must not be any knots or twists in the ropes and chains.
Ropes and chains may not be taken over sharp edges without the appropriate protective equipment; edge protection must always be used.
Asymmetric loading of the equipment must be avoided.
Ropes and chains must be shortened correctly.

18.2.2 Maintenance of load support equipment/hoists

Load support devices and hoists must be checked by an authorized expert for visible damages, deformations, wear and corrosion, cracks and breaks. This check must be done in fixed time intervals, but at least once a year. For the case of unacceptable failures, the respective device must be withdrawn from further use. When carrying out maintenance on devices, it is forbidden to make any change affecting the function and the load capacity of the device.

18.2.3 Service limits for load support equipment/hoists

When exposed to high or low temperatures, the capacity of load support equipment and hoists must be reduced accordingly.

18.3 Transport on vehicles and ships

When transporting gensets on trucks or on board ships, an appropriate intermediate layer between the loading platform and the base frame must be provided. Providing anti-slip mats or blocks made of hard rubber or wood is recommended. In addition, it is necessary to attach tensioning straps, lashing chains, mounting links and cradles to keep the genset safe against slipping or tilting. When transporting, the genset must be protected from the effects of weather using an appropriate transport cover. A package for carrying overseas will be provided for marine transport.

18.4 Reloading and unloading

Gensets are normally reloaded and unloaded using mobile cranes. As far as the choice of hoists is concerned, the same notes, rules and instructions apply for the loading of gensets as mentioned per item 18.2.

18.5 Storage of gensets and system components

Due to project requirements, gensets, switchgears and system components might have to be stored until they are installed. The following points should be observed during storage:
• the storage area must be dry and properly ventilated
• the storage area must be heated if the temperature is likely to fall below the dew point due to daily or seasonal change
• the storage area must be frost-proof

On the technical data sheets for the specific components, storage temperatures are indicated which depend on the materials installed in the components. In particular seals made of elastomers grow brittle as a consequence of frost and can be easily destroyed.
For switch cabinets with semiconductor electronic circuits, storage temperatures in the range from -10 to +50 °C are indicated.

Especially during transport and also during storage in harbors or at hauler's, it is not always possible to comply with the conditions described above. We accept no liability for damages caused by frost or dampness.

Corrosion protection is applied to the inside and outside of the diesel and gas engines for a period of 24 months. If the engine is stored for longer than the protection allows, an additional protection treatment is necessary. The length of protection provided is valid only if the storage conditions described above are complied with.

Generators must be rotated every 6 months, regardless of whether they are individually stored or installed in a genset.

System components which are installed in the open air during operation can also be stored in the open air. These are, for example, ventilator coolers or exhaust silencers.

### 18.6 Positioning and placement on the foundation

The positioning of a genset is described for a genset with an engine such as the TCG 2032 V16.
Further assembly notes on the transport and installation of gensets can be found in the operating instructions of the relevant order documentation.

#### 18.6.1 Preparations for positioning

In normal conditions, the genset has to be pulled onto the foundation via the access opening of the engine room. It is recommended to provide a two-track ramp with covering steel plates and gravel below. The ramp is arranged in the longitudinal direction of the foundation; the upper edge of the ramp is in alignment with the top of the foundation. The free accessible length of the ramp on the outside of the engine room must be at
least the full length of the genset in order to place the complete genset on the ramp. Before placing the genset on the ramp, steel rollers are arranged at the four corners of the base frame. See figure 18.2.

Fig. 18.2 Preparations for the positioning

1. Foundation
2. Steel plates
3. Gravel bed
4. Steel roller
18.6.2 Pulling the genset onto the foundation

After placing the genset on the ramp, two ropes with winches will be attached at the front end of the base frame. The ropes are to be fastened to the base frame using shackles. For fastening the opposite ends of the ropes, fixing points can be provided at the opposite wall. With use of the winches, the genset can be pulled to its final position on the foundation. See also Figure 18.3. Even when placing the genset onto the ramp, attention should be paid to alignment of the genset’s longitudinal axis to the longitudinal axis of the foundation.

Fig. 18.3 Pulling the genset

18.6.3 Placing the genset on the foundation

After maneuvering the genset to its final position on the foundation it must be placed on the foundation. At least four hydraulic jacks have to be placed below the base frame. By using the hydraulic jacks, the genset can be lifted uniformly (see Figure 18.4). After removal of the steel rollers, the elastic mounts can be bolted to the base frame. When lowering the hydraulic jacks, the genset’s weight will be absorbed by the elastic mounts. To get equally balanced load on the spring elements, they have to be adjusted with regard to the individual alignment instruction (see Figure 18.5 and 18.6).
Fig. 18.4 Arrangement of the hoist cylinder

1 Hoist cylinder

Fig. 18.5 Arrangement of the spring elements

1 Hoist cylinder
Fig. 18.6 Placing the genset on the foundation

1 Hoist cylinder
18.7 Transporting and setting up containers

In the case of container systems, the genset is ready mounted and installed in the container. System components such as exhaust silencers and exhaust heat exchangers are arranged on a common frame made from square tubes on the container roof. These frames are located loose on the container roof. For transporting a container system, the components located on the roof are removed and transported next to the container as separate freight. Figure 18.7 shows the container system ready mounted, Figures 18.8-18.10 show the division of the components into individual batches for transport. The system shown involves a CHP container.

**Fig. 18.7 Container system, complete**

```
1 Container
2 Inlet air components
3 Table cooler
4 Exhaust stack
5 Catalyst
6 Exhaust heat exchanger
7 Exhaust bypass
8 Exhaust silencer
9 Air-conditioning unit
10 Frame
11 Water pipe
12 Strip foundation (at customer)
```
Fig. 18.8 Container without roof structures and air-conditioner

Fig. 18.9 Components with frame
18.7.1 Lifting the container

For loading the container for transport, in the case of potential reloading and unloading at the construction site, the container must be lifted and moved suspended on a crane. The components inside the container, in particular the elastically mounted genset, are secured for transport. The genset is firmly interlocked using several threaded rods and underlays comprising hardwood blocks between the genset base frame and foundation rail. In addition to this, the genset is firmly strapped at the four corners of the base frame using tensioning straps with holding lugs attached to the container structure. Components for commissioning or other parts that are transported loosely along with the container are also secured for the transport. Nevertheless, it must be ensured that the container is lifted as evenly and horizontally as possible during hoisting. The container corner plates welded in the roof and in the floor of the container are used as load support points. The rope lengths must be chosen so that the crane hook is located in the level of the container center of gravity. The position of the container center of gravity is marked outside on the side wall of the container. See also Figure 18.11. and 18.14.
Fig. 18.11 Lifting the container with ropes
Lifting the container at upper container corner plates using ropes.

Fig. 18.12 Lifting the container with traverse
Lifting the container at upper container corner plates using a traverse.

1 Center of gravity marking
2 Container corner plate
3 Traverse
**Fig. 18.13 Lifting the container with two cranes**
Lifting the container at upper corner plates using two cranes.

**Fig. 18.14 Lifting the container with traverse**
Lifting the container at lower container corner plates using a traverse.

1. Center of gravity marking
2. Container corner plate
3. Traverse
18.7.2 Transporting containers

In most cases, the container and accessories are transported directly to the destination by truck. If plants are to be shipped overseas, the containers are transported to a seaport and loaded onto the ship. The containers are usually transported from the destination port to the installation site by truck again. When transporting the container and the components, the loads must be appropriately secured corresponding to the relevant regulations (e.g. VDI 2700), similarly to how this is described in Chapter 18.3 for the genset.
Fig. 18.16 Transporting a container with a low loader

Depending on the specifications, it can also be the case that the containers are packed in a crate for sea transport.
Both the container and the components mounted on the frame must be secured for transport. The container corner plates can be used on the top and bottom for fastening the container on the low loader.
18.7.3 Setting up containers

The container is set up either on a continuous foundation plate or several strip foundations. In the case of strip foundations, two strips are normally provided below the two longitudinal sides of the container. Depending on the arrangement of the cable outlets in the container, suitable ducts or recesses must be provided in the foundation or in the foundation strips. The implementation of the foundation, i.e. foundation height, choice of concrete grade and reinforcement, must be carried out at the customer by a structural engineer. The unevenness of the foundation should not exceed 5 mm in the longitudinal direction and 2 mm in the transverse direction.

The following points must be checked before placing the container down on the foundation:

- Check foundation for evenness and cleanliness
- Check location of the recesses for cable outlets
- Check container underside for cleanliness

After this, the container is placed down on the foundation.
After setting up the container, the components are mounted on the roof and connected. In addition, the external lines must be provided for the gas, oil, heating water circuit and the electrical connection. If any doors are stiff or jammed, the adjustment must be recalibrated at the hinges.

18.7.4 Installation instructions for containers

General installation instructions are supplied for each container plant with the documentation. Specific documents for the mounting the assemblies, foundation dimensions etc. will continue to be provided for the individual order.
Power plants layout

Chapter 19

Genset installation and alignment instructions

06-2017
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19. **Genset installation and alignment instructions**

The object of these instructions is to ensure that the genset is correctly positioned and installed in the genset room and to avoid possible consequential damage arising from incorrect installation.

19.1 **Transport and positioning of gensets**

Chapter 18, "Transport and Placement" describes what action has to be taken for placing the genset at its final position.

19.2 **Protecting the genset**

After the genset has been mounted and aligned on its foundation and before piping and cabling works can begin, the genset must be protected against dust and dirt, for example with a tarpaulin.

To protect the electronics and the bearings in the engine and generator, welding should not be carried out on the genset!

It must also be ensured that components installed at the genset, such as transmitters, temperature sensors or attachments such as pumps, filters, etc. are not used as "conductors" during the installation.

**In order to maintain the value and reliability of the system, we draw your attention to the following points:**

- The genset room as well as the switchgear room should as far as possible be kept free from dust. Dust reduces the service life of the engine, shortens the lifetime of the generator and impairs the functioning of the control system.

- Condensation and dampness in engine rooms encourage corrosion of both the genset and the switchgear. High-quality CHP plant installations require dry, preferably heated rooms (above 5 °C).

- After the test run at the factory, the engine will receive interior corrosion protection as per our works standard. The standard treatment lasts 24 months. If the genset is to remain shut down for an extended period, the insulation resistance of the generator must be checked before commissioning. In the event of dampness, the generator must be dried (stationary heating or other suitable means).

- If the genset is set up in a container, the genset must be fully emptied (risk of freezing) and secured against movement for storage or transportation.

19.3 **Elastic mounting**

For the elastic mounting of the gensets, steel bellows are used as standard. These are equipped with a leveling device as standard. Beneath the footplate of the bearing element is a rubber plate which can be set directly onto the foundation. It must be ensured that the foundation surface is free of grease, lube oil, fuel or
other contaminants. The foundation surface should be level ±2 mm and have a roughness equivalent to standard concrete foundations. The foundation must not be tiled.

In the TCG 3016 series of gensets the gas engine and generator are connected rigidly via a flange housing. The gas engine and generator unit is mounted on the base frame with rubber elements. The base frame is installed rigidly on the foundation.

It is not necessary to screw down or dowel the spring elements with the foundation. However, the 4 bearing elements can be screwed (doweled) at the corner points of the genset to fasten the genset to the foundation, or, in the container installation, they can be fastened with steel stoppers.

The quantity and the arrangement of the bellows is shown in the order-specific genset drawing, as is the note on the installation and alignment specification of the steel spring used.

For those regions most at risk of earthquakes, there are special requirements for mounting the gensets. For those installations, the mounts must be doweled to the foundation. A recalculation of this connection must be carried out by a structural engineer.

If a genset is installed in a container, a transportation lock must be provided between the genset's base frame and the foundation plates in the container base. This will prevent movement of the genset on the steel bellows. The transportation locks must be removed when commissioning the genset.

19.4 Torsionally flexible coupling

After aligning the genset on the foundation, the axial and radial runout of the coupling must be checked. This is performed using dial gauges. The positioning of the dial gauges is illustrated in principle in Fig. 19.1. For dimensions, alignment tolerances and screw torque settings, please refer to the order-specific genset drawing.

The alignment is corrected by moving the generator or by placing shims beneath the foot of the generator.
Fig. 19.1 Positioning the dial gauges

1. Reference dimension for checking axial runout
2. Flywheel
3. Coupling

19.5 Rubber expansion joints and hoses

Expansion joints and hoses are used in the system to elastically decouple media-bearing pipes from the elastically mounted genset. Expansion joints and hoses are also used to insulate structure-borne noise, which would otherwise be transmitted through the pipes into the building. Furthermore, rubber expansion joints and hoses must be provided in the external piping system in order to compensate heat expansion. The quantity of expansion joints to install depends on the pipe routing itself and the heat expansion caused by the temperature of the operating media inside the pipe.

Note:
Before installing expansion joints and hoses, the genset must be aligned on its foundation as per Chapter 19.3 (Elastic mounting elements). The external pipes are connected without filling the engine previously with water and lube oil. After filling the water and lube oil, the genset only moves down an additional 1 - 2 mm on the engine side. If necessary, the height-adjustable elastic mounts can be readjusted.
Listed in Tables 19.1 and 19.2 are the flange connection dimensions and the specific values for the expansion joints.

Expansion joints with the bellows material EPDM (Ethylene Propylene Diene Monomer Rubber) are used for installation in the cooling water systems. In these types the bellows are provided with an orange/blue marking. When this bellows material is used, only oil-free cooling water additives may be used.

When used in lube oil systems, expansion joints with the bellows material NBR (nitrile rubber) are used, with this only applying to the TCG 2032 series. In these types the bellows are provided with a red/blue marking.
**Table 19.1 Expansion joints with flanges to EN 1092-1**

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*1) Counter flanges as per EN 1092-1-PN16 with screws and self-locking nuts as per DIN 985, but without any seals

For DN 200, counter flanges as per EN 1092-1-PN10

Installation Notes No.: 6.000.9.000.242 sheet 1-4
Pressure stages

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<tr>
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</table>

(*) In case of loads produced by jerks, the max. operating pressure should be set 30% lower

Balk material: EPDM
Operating media: Cooling water with oil-free additives for anti-freeze and corrosion protection

Balk material: NBR
Operating media: Lube oil

1 Surfaces machined by cutting
2 Rating plate orange/blue (EPDM), red/blue (NBR)

In the case of interfered motions, these values have to be enquired from the manufacturer. See also Chapter 19.5.1.4
Table 19.2 Expansion joints with flanges to VG 85356

<table>
<thead>
<tr>
<th>5</th>
<th>6</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tr>
<td>DN</td>
<td>PN</td>
<td>ØD</td>
<td>Øk</td>
<td>nxØd2</td>
<td>b</td>
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<tr>
<td>[mm]</td>
<td>[bar]</td>
<td>[mm]</td>
<td>[mm]</td>
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<td>40</td>
<td>42</td>
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<td>172</td>
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<td>200</td>
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<td>10xØ11</td>
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<tr>
<td>150</td>
<td>159</td>
<td>16</td>
<td>226</td>
<td>202</td>
<td>12xØ11</td>
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Legend for column designations

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<th>Sign</th>
<th>Designation</th>
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<tbody>
<tr>
<td>1</td>
<td></td>
<td>Flange dimensions like VG 85356 Part 1</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Bellows</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Movement absorption (without overlay)</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Expansion joint</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>DN Nominal diameter</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Pipe diameter, external</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>ØC Sealing surface</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>W Shaft diameter (depressurized)</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Suppression</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Extension</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Lateral ± angular</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>Weight</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure stages</td>
<td>°C</td>
<td>+ 60</td>
</tr>
<tr>
<td>-----------------</td>
<td>----</td>
<td>------</td>
</tr>
<tr>
<td>Temperature load up to</td>
<td>bar</td>
<td>16</td>
</tr>
<tr>
<td>Max. permissible operating pressure *)</td>
<td>bar</td>
<td>≥48</td>
</tr>
<tr>
<td>Test pressure (+20 °C)</td>
<td>bar</td>
<td>23</td>
</tr>
<tr>
<td>Burst pressure</td>
<td>bar</td>
<td>≥48</td>
</tr>
</tbody>
</table>

* in case of loads produced by jerks, the max. operating pressure should be reduced by 30%!

Balk material: EPDM
Operating media: Cooling water with oil-free additives for anti-freeze and corrosion protection

Balk material: NBR
Operating media: Lube oil

1 Surfaces machined by cutting
2 Rating plate orange/blue (EPDM), red/blue (NBR)

In the case of interfered motions, these values have to be enquired from the manufacturer. See also Chapter 19.5.1.4
To ensure correct installation, the following instructions must be observed:

19.5.1 Rubber expansion joints

Installation notes for Stenflex rubber expansion joints type AS-1

19.5.1.1 Storage

Expansion joints must be stored in a clean and dry condition, protected from all damage, and must not be rolled using the bellows. In the case of storage and installation in the open air, they must be protected from intense sunlight, such as through the use of a covering sheet.

19.5.1.2 Arrangement and installation

The expansion joint should be arranged in an accessible location where it can be monitored.
Before starting the installation, the gap into which the joint is to be fitted must be checked and the expansion joint compressed to the correct installation length BL.
Before the expansion joint is installed, it must be checked in its consistency and, with regard to the state of the rubber bellows, if for example a strong embrittlement caused by the high temperature has occurred.

Fig. 19.2

Flange with smooth sealing surface through to internal diameter

The higher the operating temperature on the expansion joint, the faster the elastomer will age and embrittle (in other words, harden) and the rubber bellows have a tendency to form cracks.
If a strong crack formation has occurred on the surface, the expansion joint should be replaced for safety reasons.
Noting the maximum permissible amount of movement which may be accommodated (and which must not be exceeded in operating mode), the expansion joint must be installed without torsion. The joint should preferably be subjected to compression.

Attention should also be paid to the effect of external heat radiation. The bores in the flanges must remain in alignment.

When using DIN welding neck flanges and VG flared flanges, no additional seals are required as the rubber lip is sufficient. Other flange designs are not permissible owing to the risk of damage to the rubber lip.

**19.5.1.3 Assembly**

**Fig. 19.3**

\[A = \text{overall length} = \text{installation length}\]

The expansion joints are installed using normal hexagon screws and self-locking hexagon nuts as per DIN 985.

Only DIN welding neck flanges or VG flared flanges are to be used as counter flanges.

The nuts should be located on the counter flange side, installation type (1). If this is not possible, the length of the screws should be selected so that the measurement X is not less than 15 mm, installation type (2). (See Fig. 19.3).

Installation type (1) should be preferred.

The screws should be tightened evenly several times on a diagonally alternate basis; if necessary, they should be retightened slightly after initial commissioning. Excessive tightening can crush the rubber lip.
To avoid tool damage to the rubber bellows, the wrench on the bellows side should be held steady whilst the wrench on the counter flange side is turned.

In order not to destroy the rubber seal by overtightening the flanges, Table 19.3 with the tightening torques has to be observed.

**Fig. 19.3 Tightening torques for rubber expansion joints**

<table>
<thead>
<tr>
<th>Nominal width DN</th>
<th>Tightening torque [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>65</td>
<td>10</td>
</tr>
<tr>
<td>80</td>
<td>10</td>
</tr>
<tr>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>125</td>
<td>15</td>
</tr>
<tr>
<td>150</td>
<td>15</td>
</tr>
</tbody>
</table>

The tightening torques listed apply to new expansion joints. The values can be exceeded by 50 % if necessary.

After 24 hours operation, the deformation has to be compensated by retightening the screws.

The installation notes of the expansion joint supplier must be observed.

### 19.5.1.4 Installation instructions for rubber expansion joints in gas engine gensets

The values for permissible suppression, stretch, lateral and angular movement absorption given in Tables 19.1 and 19.2 are all maximum specifications for non-overlaid deflections. When installing the expansion joints on the gas engine genset, the values given in Fig. 19.4 must be observed. Adhering to these installation dimensions guarantees that the genset's deflections can be absorbed both during operation and during start and stop procedures without overstraining the expansion joints.
Fig. 19.4 Installation of expansion joints

![Diagram of expansion joint installation](image)

1 Fixed point

### Maximum permissible installation dimensions

<table>
<thead>
<tr>
<th>DN</th>
<th>( l_1 ) [mm]</th>
<th>( l_2 ) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>32 - 65</td>
<td>125 ± 5</td>
<td>3</td>
</tr>
<tr>
<td>80 - 175</td>
<td>150 ± 5</td>
<td>3</td>
</tr>
<tr>
<td>200</td>
<td>175 ± 5</td>
<td>3</td>
</tr>
</tbody>
</table>

The following points should be noted when installing the expansion joint:

- Before welding the counter flange, disassemble the rubber expansion joint.
- Only screw in fixing screws from the rubber bellows (screw head on rubber bellows side).
- Pretension flange on a diagonally alternate basis until it rests against metal.
- Provide fixing point at a distance of max. 3 x DN.
- Torsion (twisting) of the rubber expansion joint is not permissible.
- Do not apply paint to the rubber bellows.
19.5.1.5 Arrangement of pipe brackets

When arranging expansion joints, pipe brackets/guides must be always provided before and after the joint. For expansion joints that are only installed for the decoupling of vibrations (e.g. the joints of an elastically mounted genset) fixing points must be provided at each side of the expansion joint.

Expansion joints installed for the compensation of heat expansions in the pipe generally have a pipe bracket as a fixing point on one side and a pipe guide as a free-running point on the other side. Depending on the individual installation situation, it might be feasible to provide free-running points on both sides. The distance between the fixed or free-running point and the expansion joint should not exceed 3 x DN.

See also Chapter 20.5 Pipe brackets/supports

19.5.1.6 Protective measures after installation

After installation, expansion joints should be covered as protection against welding heat (e.g. weld spatter, beads) and external damage. The expansion bellows must be kept clean and must not be painted.

19.5.1.7 Underpressure loading

If an expansion joint is to be subjected to negative pressure (vacuum), it must under no circumstances be stretched when it is installed. It is better to compress the joint slightly, making it more vacuum-resistant. However, special measures will be called for here which must be enquired for separately. The installation instructions of the manufacturer must be complied with here.

19.5.2 Hose lines

Installation notes for rubber hoses
DN 8 to DN 40 (flame-proof)

19.5.2.1 Storage

Hoses must be stored in a clean and dry condition and above all protected against external damage. They should not be dragged on the ground or over sharp edges.
Lay the hose out straight by unrolling the coil of the hose. Pulling on one end of the hose ring will bend the hose beyond its minimum permissible bending radius and subject it to an impermissible torsional stress.
Arrangement and installation 19.5.2.2

Hoses should be arranged in an accessible location where they can be monitored.
Hoses should not come into contact with one another or with other objects during operation.
Hoses must not be bent beyond their permissible bending radius (Table 19.4). It is not permissible to overbend or stretch the hoses.

Fig. 19.6

1  incorrect  A  Installation length too short
2  correct  B  Installation length satisfactory
Install hose without tension. Axial compression is not permissible. The braiding detaches itself from the hose and pressure resistance is no longer guaranteed.

Hoses must not be bent at sharp angles or buckled, i.e. the hose must not be kinked. No movements or bending stresses must act directly on connections (screw connections). The so-called neutral part of the hose ends must be of adequate size.

If necessary, standard commercially available elbows, manifolds or ring-type screw connections must be provided at the connection ends. When selecting the connecting parts, the stress from pressure temperature and type of operating media must be observed. In the event of movement, the hose must be mounted so that its axis lies in the same plane as the direction of movement in order to prevent torsion.

The So Ms 59 F 50Z (= special brass) soldered connectors on the hose screw connections can be removed from the connections and hard-soldered to the respective pipe ends.

After determining the gap in which to install the joint between the pipes to be connected, first solder the connector in place on one side, then check the possible bending radius for the hose before soldering the connector on the other side.

The permissible bending radii listed in the following Table 19.5 must be observed.

The ends of the connection pipes must be cut off precisely at right-angles to the axis of the pipe.
The minimum bending radii specified in Table 19.4 relate to rigidly laid hoses. If the movement in the hose (where the bending radius is tight) is very often repeated (= continuous operation), it is recommended that an attempt be made to increase the radius (if necessary, by using turning knuckles). This will prevent the hose from kinking and extend its service life.

Fig. 19.7

1. Connection pipe
2. Soldered connector
3. Union nut
4. hard-soldered
5. Hose line
Table 19.4

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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<td>10</td>
<td>8</td>
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<td>75</td>
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<td>70</td>
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<td>10</td>
<td>38</td>
<td>OLNWV 2298</td>
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<tr>
<td>11</td>
<td>20</td>
<td>500</td>
<td>130</td>
<td>21.5</td>
<td>25x1.5</td>
<td>8</td>
<td>25</td>
<td>10</td>
<td>50</td>
<td>80 (14)</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>700</td>
<td>180</td>
<td>21.5</td>
<td>35x2.0</td>
<td>8</td>
<td>25</td>
<td>10</td>
<td>50</td>
<td>90 (15)</td>
</tr>
<tr>
<td>12</td>
<td>32</td>
<td>700</td>
<td>240</td>
<td>23.5</td>
<td>40x2.0</td>
<td>10</td>
<td>22</td>
<td>10</td>
<td>45</td>
<td>80</td>
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<td>20</td>
<td>500</td>
<td>130</td>
<td>21.5</td>
<td>25x1.5</td>
<td>8</td>
<td>25</td>
<td>10</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>700</td>
<td>180</td>
<td>21.5</td>
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<td>25</td>
<td>10</td>
<td>50</td>
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<tr>
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<td>10x1.0</td>
<td>5</td>
<td>215</td>
<td>170</td>
<td>510</td>
<td>90 (14)</td>
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<td>150</td>
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<td>150</td>
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</tr>
<tr>
<td></td>
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<td>700</td>
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<td>45x2.0</td>
<td>10</td>
<td>50</td>
<td>40</td>
<td>120</td>
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*1) rmin = smallest bending radius
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<tr>
<td>2</td>
<td>ØD</td>
<td>ØD for pipe</td>
</tr>
<tr>
<td>3</td>
<td></td>
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<td>9</td>
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<td>short-term</td>
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<tr>
<td>10</td>
<td></td>
<td>Diesel fuel</td>
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<tr>
<td>11</td>
<td></td>
<td>Diesel fuel, water and lube oil</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Sea water</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>Lube oil, compressed air and water</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>Diesel</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>Water</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>Lube oil</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>Compressed air</td>
</tr>
</tbody>
</table>
The following graph (Fig. 19.7) shows - dependent on the bending angle of the hose - the bending factor by which the minimum bending radius must be multiplied to determine the permissible bending radius for continuous operation.

Fig. 19.8

1 Soldered connector
2 Union nut
3 up to DN 60 press version
   From DN 70 screw version
4 Hose line
5 Ordering length L

Fig. 19.9

A Bending angle
B Bending factor
19.5.2.3 Installation

When installing the hose, tighten the connection on one side only. To begin with, leave the connection at the other side loosely fixed. Move the empty hose 2 or 3 times in the desired direction, to allow it to align itself without twisting, then tighten the loose end as well. In the case of hoses with screw connections, it is essential to use a second wrench to hold the connection (Fig. 19.8).

Fig. 19.10

Connect hose without twisting.
Use a second wrench to hold rotating threaded connections.

19.5.2.4 Pipe brackets

When arranging hose lines, fixed and free-running points must always be provided upstream and downstream of the hose line. The distance between the fixed or free-running point and the hose should not exceed 3 x DN.

19.5.2.5 Protective measures after installation

After installation, hose lines should be covered as protection against welding heat (e.g. welding spatter, beads) and external damage. The hose line must be kept clean and must not be painted.

19.5.2.6 Type approval test

The hoses are flame resistant (flame-proof) and fulfil the requirements of all classification organizations.
19.5.3  Exhaust expansion joints

Installation instructions for axial expansion joints and axial double expansion joints for the exhaust systems of stationary systems

19.5.3.1 Storage

Axial expansion joints must be stored in a clean and dry condition, protected from all damage, and must not be rolled using the bellows. Always lift expansion joints for transportation.

19.5.3.2 Arrangement and installation

The expansion joint should be arranged in an accessible location where it can be monitored. Before starting the installation, the gap into which the joint is to be installed must be checked to ensure the correct installation length.

Noting the maximum permissible amount of movement which may be accommodated (and which must not be exceeded in operating condition), the expansion joint must be installed so that it is not subjected to torsion stresses either during installation or during operation due to adverse pipe tension. The joint should preferably be subjected to compression. The ideal installation is when the expansion joints are installed free of tension as far as possible whilst the system is in operation.

The holes in the flanges must line up, and the seal must be located centrally. The exhaust expansion joints supplied by CES have loose flanges with flared tube ends. The flared tube ends can also assume the function of the seal.

It must be assured that the pipes to be connected are also in precise alignment.

When specifying the length of the expansion joints, please note these different terms.

The **overall length** is the length of the expansion joints as generally supplied by the manufacturer (= delivered length). The overall length is indicated on the rating plate of the expansion joint.

The **installation length** comprises the overall length with pre-tension (stretch + or compression -) according to Fig. 19.9 and Fig. 19.10.
In cold condition, the expansion joint should be installed half pre-tensioned (either half stretched + or half compressed -), dependent on how the expansion joint is to be used. This is recommended even if the axial movement of the expansion joint is not to be fully utilized. For example, if total expansion is only 30 mm
whilst the expansion joint allows for 66 mm of expansion, it is better - likewise in terms of service life - to preload the expansion joint to ± 15 mm rather than -30 mm.

19.5.3.2.1 Installation on the engine (turbocharger)

An alignment is necessary when connecting the exhaust pipe on the system side to the exhaust expansion joint on the engine side. A poor alignment of the engine-side exhaust expansion joint leads to impermissible forces acting on the housing of the exhaust turbocharger.

To avoid the above problems, we provide installation specifications in the form of a drawing for the TCG 2032, TCG 2020 V12 and V16 with the turbocharger type TPS 52 and for the TCG 2020 V20 with the turbocharger type TPS 48.

The drawings for the installation specifications are:

- TCG 2020 V20/TPS 48: 1242 0623 UB
- TCG 2020 V12/V16/TPS 52: 1242 0619 UB
- TCG 2032 V16: 1228 2504 UB

It must always be ensured that there is no stress imposed on the engine, and in particular on the turbocharger, due to heat expansion in the connecting pipework. In operation, the expansion joint should accommodate only the vibrations in the genset on its elastic mountings (Fig. 19.11). The expansion joint must be mounted at the turbocharger in such a way that the expansion joint returns to its overall length (delivered length) when the exhaust line warms up. The following fixed point of the exhaust line must be arranged directly after the expansion joint.
Fig. 19.13 Arrangement of the fixed point after the engine in the exhaust line

1 Fixed point
2 Axial expansion joint
3 Turbocharger
4 Elastically mounted genset
5 Free-running point (pipe guide)

19.5.3.2.2 Installation in the pipe section

To determine heat expansion in a pipe, the following rule of thumb applies:
For mild steel approx. 1 mm heat expansion per meter of pipe and per 100 °C.
For stainless steel approx. 2 mm heat expansion per meter of pipe and per 100 °C.

That means that, for example for a 1 meter section of pipe at 500 °C, the heat expansion is approx. 5 mm for mild steel and 10 mm for stainless steel.

Normally, axial expansion joints are fitted in an exhaust pipe to accommodate the heat expansion. The arrangement of the expansion joints will be shown on the installation plan for the respective order, whereby the installation guidelines laid down by the manufacturer must be observed. It will generally be adequate to continue the exhaust line as illustrated in Fig. 19.12.
Fig. 19.14 Fixed supports, loose supports and expansion joints in an exhaust line

1 Engine
2 Expansion joint after engine
3 Fixed point after engine
4 Free-running point/pipe guide
5 Expansion joint
6 Silencer
7 Fixed point
19.5.3.3 Installation

Check that the bellows corrugations are free from foreign bodies (dust, cement, insulation material), first inside before installation and then outside after installation.
The expansion joints are fitted using normal hexagon screws and nuts.
Smooth flanges or flared flanges are used as counter flanges. The nuts must be fitted on the counter flange side, see Fig. 19.13.

Fig. 19.15

A Overall length

The screws should be tightened evenly several times on a diagonally alternate basis; if necessary, they should be retightened slightly after initial commissioning.

To avoid tool damage to the expansion joint, the wrench on the bellows side should be held steady whilst the wrench on the counter flange side is turned.
For dimensions and connection sizes, please refer to Fig. 19.14 and Table 19.5.
Fig. 19.16

A Axial movement of bellows
B Lateral movement of bellows
Table 19.5

<table>
<thead>
<tr>
<th>DN</th>
<th>a</th>
<th>l₀</th>
<th>l</th>
<th>DA</th>
<th>LK</th>
<th>B</th>
<th>BO</th>
<th>b</th>
<th>N</th>
<th>-</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>Units</td>
<td>M</td>
<td>kg</td>
</tr>
<tr>
<td>100</td>
<td>50</td>
<td>6</td>
<td>1.0</td>
<td>118</td>
<td>60</td>
<td>2x47</td>
<td>210</td>
<td>170</td>
<td>18</td>
<td>147</td>
<td>14</td>
</tr>
<tr>
<td>100</td>
<td>80</td>
<td>12</td>
<td>2.5</td>
<td>184</td>
<td>60</td>
<td></td>
<td>240</td>
<td>200</td>
<td>18</td>
<td>178</td>
<td>10</td>
</tr>
<tr>
<td>125</td>
<td>50</td>
<td>7.7</td>
<td>0.2</td>
<td>140</td>
<td>75</td>
<td>272</td>
<td>265</td>
<td>225</td>
<td>18</td>
<td>202</td>
<td>10</td>
</tr>
<tr>
<td>125</td>
<td>200</td>
<td>114</td>
<td>2.0</td>
<td>340</td>
<td></td>
<td></td>
<td>320</td>
<td>280</td>
<td>18</td>
<td>258</td>
<td>16</td>
</tr>
<tr>
<td>150</td>
<td>50</td>
<td>6.9</td>
<td>0.2</td>
<td>145</td>
<td>78</td>
<td></td>
<td>375</td>
<td>335</td>
<td>18</td>
<td>312</td>
<td>16</td>
</tr>
<tr>
<td>150</td>
<td>200</td>
<td>101.1</td>
<td>2.0</td>
<td>350</td>
<td>286</td>
<td></td>
<td>440</td>
<td>395</td>
<td>22</td>
<td>365</td>
<td>16</td>
</tr>
<tr>
<td>200</td>
<td>50</td>
<td>5.1</td>
<td>0.2</td>
<td>150</td>
<td>73</td>
<td>291</td>
<td>490</td>
<td>445</td>
<td>22</td>
<td>415</td>
<td>16</td>
</tr>
<tr>
<td>200</td>
<td>200</td>
<td>81.2</td>
<td>2.0</td>
<td>370</td>
<td></td>
<td></td>
<td>540</td>
<td>495</td>
<td>22</td>
<td>465</td>
<td>16</td>
</tr>
<tr>
<td>250</td>
<td>50</td>
<td>3.6</td>
<td>0.1</td>
<td>150</td>
<td>65</td>
<td>286</td>
<td>595</td>
<td>550</td>
<td>22</td>
<td>520</td>
<td>16</td>
</tr>
<tr>
<td>250</td>
<td>200</td>
<td>64.5</td>
<td>1.9</td>
<td>370</td>
<td></td>
<td></td>
<td>645</td>
<td>600</td>
<td>22</td>
<td>570</td>
<td>16</td>
</tr>
<tr>
<td>300</td>
<td>50</td>
<td>3.3</td>
<td>0.1</td>
<td>150</td>
<td>69</td>
<td>285</td>
<td>755</td>
<td>705</td>
<td>26</td>
<td>670</td>
<td>20</td>
</tr>
<tr>
<td>300</td>
<td>200</td>
<td>54.4</td>
<td>1.6</td>
<td>365</td>
<td></td>
<td></td>
<td>860</td>
<td>810</td>
<td>26</td>
<td>775</td>
<td>20</td>
</tr>
<tr>
<td>350</td>
<td>50</td>
<td>3.3</td>
<td>0.1</td>
<td>155</td>
<td>74</td>
<td>272</td>
<td>975</td>
<td>920</td>
<td>30</td>
<td>880</td>
<td>20</td>
</tr>
<tr>
<td>350</td>
<td>200</td>
<td>48.1</td>
<td>1.4</td>
<td>355</td>
<td></td>
<td></td>
<td>975</td>
<td>920</td>
<td>30</td>
<td>880</td>
<td>20</td>
</tr>
</tbody>
</table>

*1) without counter flange, screws and nuts
The specified values apply at room temperature; in operating mode, lower values are to be expected. At temperatures of up to 300 °C, deviations may be disregarded for practical purposes.

For correction values $K_{ΔJ}$ for higher temperatures, please refer to Table 19.6.

The total of all relative stresses must not exceed 100 % of the temperature factor $K_{ΔJ}$.

**Legend for column designations**

<table>
<thead>
<tr>
<th>Position</th>
<th>Sign</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Technical data - axial expansion joint</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Flanges DIN 2501 PN 6</td>
</tr>
<tr>
<td>3</td>
<td>DN</td>
<td>Nominal size</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>Nominal accommodated movement over 1000 load cycles</td>
</tr>
<tr>
<td>5</td>
<td>L0</td>
<td>Overall length unstressed</td>
</tr>
<tr>
<td>6</td>
<td>l</td>
<td>Corrugated length</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Diameter</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Screws</td>
</tr>
<tr>
<td>9</td>
<td>G</td>
<td>Weight</td>
</tr>
<tr>
<td>10</td>
<td>25N</td>
<td>Axial</td>
</tr>
<tr>
<td>11</td>
<td>2N</td>
<td>Lateral</td>
</tr>
<tr>
<td>12</td>
<td>â</td>
<td>Axial / radial</td>
</tr>
<tr>
<td>13</td>
<td>DA</td>
<td>Outer diameter</td>
</tr>
<tr>
<td>14</td>
<td>LK</td>
<td>Bolt circle</td>
</tr>
<tr>
<td>15</td>
<td>B</td>
<td>Bore</td>
</tr>
<tr>
<td>16</td>
<td>BÖ</td>
<td>Flared tube end</td>
</tr>
<tr>
<td>17</td>
<td>b</td>
<td>Sheet thickness</td>
</tr>
<tr>
<td>18</td>
<td>N</td>
<td>Quantity</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>Thread</td>
</tr>
</tbody>
</table>
Likewise, where heat expansion and vibration coincide, the travel and amplitude elements must each be considered separately as per the following formula:

\[
\frac{2 \Delta_{\text{axial,Design}}}{\Delta_{\text{axial,Nominal}}} + \frac{2 \Delta_{\text{lateral,Design}}}{\Delta_{\text{lateral,Nominal}}} + \frac{\Delta_{\text{Design}}}{\Delta_{\text{Nominal}}} \leq K_{\Delta} \times 100 \%
\]

Nominal: Nominal value from Table 19.5
Design: Maximum movement in operation

An expansion joint comprising multi-wall bellows 1.4541 (X6 CrNiTi 18 9) and flared flange RST 37-2 may be used at operating temperatures of up to 550 °C.

The expansion joint only fully undertakes one of the indicated movements. The operating pressure may be up to 1 bar (PN1).

The installation length (overall length + pre-tension) is dependent on the total system-side expansion. The overall length \( L_0 \) refers to the neutral position.

**Tab. 19.6 Temperature influence on the available movement**

<table>
<thead>
<tr>
<th>( J ) °C</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>400</th>
<th>500</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>( K_{\Delta} )</td>
<td>--</td>
<td>1.0</td>
<td>0.85</td>
<td>0.8</td>
<td>0.75</td>
<td>0.7</td>
</tr>
<tr>
<td>Material</td>
<td>1.4541</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**19.5.3.4 Arrangement of pipe brackets in the exhaust line**

When arranging expansion joints, pipe brackets must always be provided before and after the expansion joint, otherwise the pipe may bend out sideways. Depending on the installation situation, the pipe brackets can be arranged as fixed and/or free-running points. The distance between the fixed or free-running point and the expansion joint should not exceed 3 x DN of the pipe.

When doing this, it must be ensured that the fixed points are actually fixed. The elasticity of a fixed point should not be so great as to allow the exhaust line to move a few millimeters before it is actually held tight.

Free-running points (pipe guides) are pipe clamps which surround the pipe but allow it to slide without tension. To avoid high levels of friction resistance, possible contamination or obstructions must be prevented between the pipe guide and the pipe.

---

1 Witzenmann, "Kompensatoren" p. 99, 1990
Depending on the weight and size of the pipe, it may be necessary to fit extra pipe brackets.

**19.5.3.5 Protective measures after installation**

After installation, expansion joints should be covered as protection against welding heat (e.g. weld spatter, beads) and external damage. The expansion bellows must be kept clean and must not be painted.

**19.5.3.6 Insulation**

Because of the considerable heat radiation, it may under circumstances be advisable to insulate an expansion joint particularly inside the engine house. For this purpose, a sliding tube or sheet-metal sleeve should be laid around and at some short distance from the expansion joint, to prevent the insulation material from resting directly on the expansion joint, see Fig. 19.16. Otherwise there is a risk that the insulation material will jam between the sides of the bellows corrugations. For the insulation, it is recommended to use asbestos-free plaited insulation strands or matting; glass wool or diatomite should not be used because of their tendency to produce dust.

**Fig. 19.17**

![Diagram of insulation](image)

**19.6 Notes on commissioning**

Before commissioning and handover to the client, the genset should be thoroughly cleaned. The following points should be noted:

- Check the adjustment of the elastic mounting elements.
- Check the alignment of the coupling.
- Check that the expansion joints have been installed as specified.
- No tension on cooling water expansion joints.
- Hoses exhibit prescribed bending radius.
- Specified pre-tension on exhaust expansion joint.
- Cables fitted with strain relief and laid with specified bending radius.
- Air filters free from dirt and contamination.
Chapter 20

Laying pipes

06-2017
# Contents

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20.3 Notes on welding/soldering pipes 5  
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20.3.2 Hard-soldering pipes 5  
20.4 Releasable pipe connections 5  
20.4.1 Flange connections 5  
20.4.2 Screw connections with sealed thread 6  
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20. Laying pipes

20.1 General installation notes

- After bending and welding and before laying, all pipes must be cleaned inside, i.e. they must first be thoroughly steeped in an acid solution, then cleaned with an alkaline solution (soda or similar) and flushed pH neutrally with hot water. Finally, the inside of the pipes must then be treated with corrosion protection.

- When commissioning the system, all pipes must be thoroughly cleaned inside to remove dirt, scale and swarf, so as to ensure that no foreign bodies are allowed to enter the pumps, valves, heat exchangers, sensor systems and the combustion engine etc. A pressure test must be carried out.

- Where pipe diameters do not match the connections to components (pumps, compressors, radiators, etc.), they must be adapted by fitting reducers or reducer connectors. For the location and size of the connections to this apparatus, please refer to the individual component drawings.

- When installing measuring instruments (e.g. calorimeters, gas meters, etc.), the guidelines specified by the manufacturer must be observed. This applies in particular to the installation location and the inlet and outlet sections.

- In systems which are to be filled with fluids, connections for draining and filling must be available at the lowest points. At all high points, air vents must be provided. At the low points, taps for filling and draining with end cap and hose connection must be installed. At the high points, bleeding taps or automatic breathers are to be attached.

- In the case of pipes carrying gaseous media, a condensate collector with drain cocks must be provided at the lowest points. The pipes must be laid with a slope to the condensate collector.

- Copper piping is however permissible for fresh oil filling lines (pipe connections to be soldered using silver solder). As an alternative, unsheathed ERMETO steel piping may be used (pipe connections generally assembled using special screw connections, never welded!). After they have been laid, the fresh oil lines should be thoroughly flushed with new oil.

- Fresh oil lines of copper or steel may be compressed with oil-resistant fittings. Since the sealing material is not oil-resistant, it is not permitted to use standard fittings for the sanitary area.
20.2 Material for pipes

Table 20.1 shows an overview of materials which have to be used for the pipes by the different media:

<table>
<thead>
<tr>
<th>Operating media</th>
<th>Subdivision</th>
<th>Pipe material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distillate fuel</td>
<td></td>
<td>Steel, copper</td>
</tr>
<tr>
<td>Blended fuel</td>
<td></td>
<td>Steel</td>
</tr>
<tr>
<td>Natural gas, mine gas</td>
<td></td>
<td>Steel, galvanized steel, between gas control line and engine steel or stainless steel; these lines must be absolutely &quot;clean&quot;.</td>
</tr>
<tr>
<td>Biogas, sewage gas, landfill gas,</td>
<td></td>
<td>Generally stainless steel</td>
</tr>
<tr>
<td>associated gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>Engine circuit, mixture cooling circuit, charge air circuit, heating circuit, emergency cooling circuit, raw water circuit</td>
<td>Generally steel, depending on the water quality, higher-grade materials may have to be used, for example sea water in the emergency cooling/raw water circuit</td>
</tr>
<tr>
<td>Lube oil, hot engine oil bypass pipes,</td>
<td></td>
<td>Stainless steel</td>
</tr>
<tr>
<td>Fresh oil filling pipes and waste oil</td>
<td></td>
<td>Steel, copper, stainless steel</td>
</tr>
<tr>
<td>pipes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressed air</td>
<td>Starter pipes</td>
<td>Stainless steel</td>
</tr>
<tr>
<td></td>
<td>Filling pipes</td>
<td>Steel</td>
</tr>
<tr>
<td></td>
<td>Control air pipes (low pressure)</td>
<td>Steel, copper</td>
</tr>
<tr>
<td>Exhaust gas</td>
<td>Operation with natural gas, mine gas</td>
<td>In front of AWT and interior installation: heat-resistant steel (e.g. 15 Mo 3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Behind AWT and outdoor installation: stainless steel</td>
</tr>
<tr>
<td></td>
<td>Operation with biogas, sewage gas, landfill gas, associated gas</td>
<td>Stainless steel (e.g. 1.4571)</td>
</tr>
<tr>
<td></td>
<td>In front of catalytic converter</td>
<td>Always stainless steel 1.4571</td>
</tr>
<tr>
<td>Condensate</td>
<td>With content of acid components</td>
<td>Stainless steel</td>
</tr>
<tr>
<td></td>
<td>Rest</td>
<td>Steel, copper, galvanized steel</td>
</tr>
</tbody>
</table>
When using materials other than those specified in Table 20.1, technical approval from the head office is required.

20.3 Notes on welding/soldering pipes

Welded connections form a homogeneous part of the piping and guarantee absolute impermeability during operation. They represent the most economical method of connecting pipes and are therefore used in preference to other methods. The quality of the weld joint is dependent on how the pipes are fitted together, the ends being perfectly centered, the edges being properly prepared for welding and the welding method. Attention: When performing welding work in the pipe system, it is absolutely necessary to disconnect all electrically conductive connections to the genset. Steel expansion joints on the genset must be dismantled. In the case of E weldings, the electrode mass has to be placed as near as possible to the welding point in order to ensure a good ground connection. Rubber and steel expansion joints must be covered during the welding work to avoid damages from the welding sparks.

See also Chapter 19.2.

20.3.1 Welding steel pipes

The following points should be noted:

The roughness of the severance cuts must not exceed max. Rz 100.

Permissible welding procedures as per:
DIN ISO 857-1, manual arc welding, MIG or TIG
DIN EN 439, argon inert gas, at 5-7 liter/min argon to protect weld root

Weld seam preparation as per:
DIN EN ISO 9692-1

Directive on assessment categories for irregularities
DIN EN ISO 5817 or

Filler metals
- Manual arc welding: Rod electrode DIN EN ISO 2560
- TIG: Solid rod DIN EN 440, DIN EN 439, DIN EN 1668
- MIG: Wire electrode DIN EN 440, DIN EN 439, DIN EN 1668

20.3.2 Hard-soldering pipes

Brazed joints should be manufactured in accordance with our works standard H0340.

20.4 Releasable pipe connections

20.4.1 Flange connections

Flange connections are notable for their ease of assembly and are generally used for the pipe connections at engines, pumps, heat exchangers, tanks, etc. Preference should be given to flanges which comply with
DIN 2501, PN10 or PN16; for high-pressure media (e.g. compressed air), they should have a correspondingly higher nominal pressure.

When servicing or maintaining engines or system components, it is often necessary to dismantle pipes to improve accessibility. In such cases, it is particularly recommended that flange connections be installed at suitable locations.

The materials used to seal between the flanges should be selected to suit the load imposed by the operating media itself as well as the pressure and temperature of the media. In order to avoid leaks, flange connections need to be monitored. Therefore, as far as possible, flange connections should be accessible in order to replace the seals or retighten the screws. The facility to check the connections visually must, under all circumstances, be guaranteed.

20.4.2 Screw connections with sealed thread

Whitworth pipe threads as per DIN EN 10226 are used exclusively for cylindrical, internal threaded connections to mountings, fittings, etc. and for tapered external pipe threads. To increase the sealing tightness before fitting, the threads must be packed with sealant in the form of hemp with sealing putty or plastic sealing tape.

Plastic sealing tape should be used for lube oil, fuel and gas pipes.

20.4.3 Screw pipe connections

With screw pipe connections, the sealing tightness is achieved with the aid of a progressive ring which creates a positive-fit, leak-proof pipe connection.

In such cases, exclusively precision steel pipes should be used, preferably with external diameters from 6 to 38 mm. Depending on the wall thickness and external diameter, it may be necessary to use reinforcing sleeves.

Care must be taken in tightening the progressive ring.

20.5 Pipe brackets/supports

Pipes should be fastened to consoles or walls with clamps, round steel clips, etc. In the case of pipes running horizontally, the mounting span must be selected according to the pipe diameter. In the case of pipes subject to expansion because of the high temperature of the operating media they carry, the mounting supports must be implemented in fixed or free-running form to suit the conditions. Where appropriate, the possibility of structure-borne noise should be considered.

20.6 Insulating pipes

Depending on the temperature of the operating media they carry, pipes must be fitted with heat insulation to provide contact protection. The insulation thicknesses must be selected to avoid the surface temperatures of
the insulation exceeding 60 °C. Contact protection can also be achieved by other means, for example by fitting perforated metal sheeting or wire mesh at an appropriate distance from the hot parts.

20.7 Surface treatment, coloring

It is essential that all piping, with the exception of stainless steel pipes, is painted. For this purpose, the pipes must be thoroughly cleaned and primed to a dry film of approx. 30 μm in thickness. A top coat must then be applied with a coating thickness of approx. 40 μm.

Insofar as no particular colors are otherwise specified, the colors should be selected in accordance with DIN 2403. This standard lays down the requisite colors for pipes dependent on the media they carry.

Pipes provided with heat insulation should be coated in primer only.

Steel exhaust pipes must be painted with heat-resistant paint. A high-temperature-resistant zinc silicate-based paint should be used, preferably applied in 2 coats, each of 40 μm dry film thickness.
Power plants layout

Chapter 21

Health and safety at work, accident prevention, environmental protection

06-2017
## Contents

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21. Health and safety at work, accident prevention, environmental protection

When planning, installing and maintaining a system incorporating engine-driven gensets, the general rules governing health and safety at work and the accident prevention must be observed.
In the EU, the German Health and Safety at Work Regulations (BetrSichV) for the safety of working appliances and systems requiring monitoring have been applicable since October 03rd, 2002.
Basic health and safety requirements in the design and construction of machines are laid down in the EU Directive 2006/42/EC. The present aim is to draw attention to certain measures.

The safety regulations, which are a component of the gensets and/or system documentation, must be complied with during layout, maintenance and operation of the systems.

21.1 Scaffolding, staging, ladders

- When installing systems, it is usual for components to be installed at such heights that scaffolding or staging is required. Scaffolds and stages must be equipped with safety railings. If heavy components are to rest on the scaffolding, this must be adequate to bear the load.
- If frequently operated fittings or instruments to be read on a regular basis are installed at a height which is not normally reachable, stationary platforms must be provided.
- Only TÜV-approved ladders may be used.
- When installing series TCG 2032 engines, it is essential that engine maintenance stages are provided by the client.

21.2 Noise protection

In the engine room, when the engine gensets are operating, noise levels of above 100 dB(A) are reached. Over time, these will cause persons present in the engine room to suffer hearing damage if protective measures are not taken. Ear protection must therefore be worn in the engine room when the gensets are operating. Warning notices requiring ear protection to be worn must be provided at the entrances to the engine room.

21.3 Fire safety, escape plan

- The fuels, gaseous or liquid, used for the gensets and the engine lube oil can easily ignite in the atmosphere. Uncontrolled fuel escapes must therefore be avoided or monitored. Cleaning cloths soaked in oil or fuel must be disposed of immediately, since if these catch fire, they can easily become the cause of a major conflagration. Depending on the safety requirements for the design of the respective plant, stationary fire extinguishing facilities must be provided along with appropriate
alarm and triggering devices. There must be notices identifying the location of fire extinguishing
equipment such as e.g. manual fire extinguishers, hydrants, etc.

- The appropriate width (min. 600 mm) and height (min. 2000 mm) of escape routes must be
  observed. In case of fire in the engine room, the escape routes must be identified. An escape plan
  must be available. This is of particular importance where the engine room is located within a larger
  building.
- The statutory regulations are to be followed.

21.4 Contact protection

All components involving moving parts - in the engine room, this will primarily include the gensets with the
engine-driven generators, compressors and electric pumps - must be fitted with the appropriate protective
devices to prevent direct contact with rotating parts. The protective devices may be removed during service
and maintenance intervals only. When carrying out such works, the starters must be isolated to prevent the
engines from being started unintentionally.

When the gensets are in operation, the media bearing lines, especially the cooling water and exhaust lines,
can reach temperatures which would cause burns to the skin in the event of direct contact. These lines must
be fitted with heat insulation or with appropriate contact protection.

21.5 Emergency stop facilities

In addition to the emergency stop buttons at each genset, a secured emergency stop button must be located
at an easily accessible point in the engine room, preferably in the vicinity of the escape door, to shut down
the system in the event of a hazard.

21.6 Storage and disposal of hazardous materials

Fuels, lube oils, cooling water treatment agents, battery acid, cleaning agents, etc, constitute hazardous
materials, which should be stored in large containers, barrels or other vessels in the engine room or in an
adjacent room. The storage locations for such materials must be so designed that even if a container is
damaged, the substances cannot enter the waste water system.

21.7 Electrical protection

The VDE regulation VDE 0100 defines measures to protect against hazardous contact voltages.
It distinguishes between:

- Protection against direct contact
  Live parts of electrical operating equipment - parts carrying a voltage - must either be insulated in
  their entirety or protected against direct contact by virtue of their design, location or arrangement,
  or by way of special regulations.
- Protection in the event of indirect contact
  Even in the case of operating equipment which was fine at the time of manufacture, insulation
defects may occur due to aging or wear, as a result of which touchable, conductive parts may carry
high contact voltages (50 V and above).

Work should only be carried out on potentially live electrical installations whilst these are isolated from the
voltage supply.

In order to render the equipment voltage-free and secure, there are 5 safety rules to be followed:
- Disconnect
- Secure against reconnection
- Check that equipment is voltage-free
- Earth and short-circuit
- Cover or cordon off adjacent parts which are electrically live

The responsible supervisor must not approve the workplace for works to commence until all 5 safety rules
have been complied with.
Once work has been completed, the safety measures must be lifted.
The order to switch the equipment on must not be given until the system has been released at all workplaces
and all switch points have reported that they are ready to connect.

21.8 Accident prevention regulations for electrical systems

The accident prevention regulations must be observed!
Especially the DGUV regulation 1, Principles of prevention, and the DGUV regulation 3, Electrical systems
and equipment, must be observed. For the installation of power systems, please refer to VDE 0100
(DIN VDE 0100-xxx / IEC 60364-x-xxx) or VDE 0101 (DIN EN 61936-1 / IEC 61936-1); for operation,
DIN EN 50191, DIN EN 50110-1 or VDE 0105 applies.

Note:
Electrical systems and power installations may be installed and operated by trained personnel only.
Personnel must be specially trained in order to commission medium-voltage generators.

21.9 Risk assessments

Risk assessments have been carried out and documented for all gensets. The possibilities of a hazard
during installation, starting, operation and maintenance of the gensets are outlined and evaluated in the risk
assessments. The measures to be undertaken for limiting the hazard are also described.