GT16000
GAS-TURBINE ENGINE
FOR POWER GENERATION

BRIEF TECHNICAL DESCRIPTION

V1G59057800
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1. INTRODUCTION

"MASHPROEKT" enterprise has more than 40-years' experience in designing, manufacturing and supplying gas-turbines for navy and industrial applications. More than 2500 gas-turbine engines of 2.5 – 25 MW capacity have been manufactured in this time.

The manufactured engines in use have logged over 15,000,000 hours in total.

"MASHPROEKT" enterprise has a unique experience of installation of combined cycle power units in ocean vessels.

GT16000 gas-turbine engine has been used for power generation since 1991. General view of the engine is shown in Section 5, page 14.

GT16000 can be used for a power plant in peak, base and standby modes.

GT16000 accepts 20% power overloading when decreasing ambient temperature less than –10°C at the gas-turbine inlet. If it is the case, the gas temperature does not exceed the rated one at the turbine outlet.

GT16000 gas-turbine engine can operate at various climatic conditions such as:

- ambient temperature from –60°C to +50°C,
- up to 100% humidity non-condensing at +15°C,
- air temperature in a gas-turbine container from +5°C to +55°C,
- when raining, snowing.
2. ABBREVIATIONS

AC – alternating current
DC – direct current
GTE – gas-turbine engine
HPC – high-pressure compressor
HPT – axial high-pressure turbine
LPC – low-pressure compressor
LPT – axial low-pressure turbine
MCR – maximum continuous rate
RPM – revolution per minute (rotating speed)
PMCS – name of the monitoring software for generator metering
3. DESIGN FEATURES

3.1. Design Basis

GT16000 gas-turbine engine (GTE) was initially designed for heavy-duty marine application with extended requirements to starting and loading. The GTE has proven its reliability and durability in the harsh marine environment.

The GTE is of a three-rotor design.

Implementation of a three-rotor design with a free power turbine provides:

- self-adjustment of operating mode of compressors in a wide range of GTE shaft output,
- advanced transient performances of GTE,
- high efficiency in a wide range of GTE shaft output,
- reliable margin of gas-dynamic stability of the compressors,
- easy and quick start-up.

3.2. GTE structure

Most of welding of GTE is done by electron beam.

GTE is installed on a frame inside a container that is a heat-noise protection shroud.

GTE is of a modular design that provides easiness for service.

It is possible to perform independent maintenance or replacement of the following units:

- Low-pressure compressor
- Turbine
- Any of sixteen combustors
- Any of sixteen fuel nozzles
- Nozzle guide vanes of the high-pressure turbine first stage
- Main drive in the low-pressure compressor front case
- Lower drive box
- Lub oil unit
- Starter drive box
- Electric starters.
3.3. **Turbo-Compressors and Power Turbine**

3.3.1. Axial Turbo-Compressor: Supersonic Variable First Stage

The low-pressure turbo-compressor is formed by the nine-stage axial low-pressure compressor (LPC) and two-stage axial low-pressure turbine that brings the LPC into rotation.

The first stage of low-pressure compressor is supersonic.

The guide van of the first stage of low-pressure compressor (LPC) is self-adjustable, with its own energy independent pneumatic control system that is sensitive to the outlet pressure of the high-pressure compressor. The angular range of adjustment of the guide van is as wide as 25 degree.

The self-adjustable guide van provides high margin of gas-dynamic stability of the LPC at near-idling operating of GTE.

The adjustable guide van permits also to optimise the RPM of the LPC at near-extreme operating mode of GTE.

The high-rigid LPC drum is electron-beam welded at its stages from 4 to 8.

The high-pressure turbo-compressor is formed by ten-stage axial high-pressure compressor (HPC) and two-stage axial high-pressure turbine (HPT) that brings the HPC into rotation.

The high-rigid HPC drum is electron-beam welded at its stages from 4 to 9.

Compressor rotor blades are extensively made of titanium alloys to increase resistance against wear-and-tear and corrosion.

The power turbine is of four-stage, axial design. It is not connected to other turbines.

Nozzle guide vanes and rotor blades of the turbines are manufactured of heat-resistant alloys by high-precision investment casting that provides high precision of blade profile and stability of gas-dynamic characteristics.

The high-precision investment casting technology is used for manufacturing of rotor- and stator blades of all three turbines to create bifurcate cooling passage inside of the blades.

3.3.2. Rotating Supports and Sealing of Rotors

All rotors are supported by ball-bearings, excluding the rear rotating support of the power turbine. This support contains the titling pad thrust bearing that is capable to accommodate a large range of speed, load and oil viscosity conditions because the pads are able to assume a small angle relative to the moving collar surface.

Rotor bearings of all three rotors are installed in flexible supports with oil dampers, that reduces dynamic loads on the bearings and improves considerably vibro-acoustic performances of the engine.

The engine design incorporates an unloading system that allows to decrease axial loads on thrust ball bearings of GTE rotors.
The rotor of high-pressure turbo-compressor is made with two supports and cantilever-beam high-pressure turbine.
The high-precision labyrinth seals bring inter-stage leakage in the compressors and turbines to a negligible level, that provides high efficiency of the machine and its low oil consumption.

### 3.4. Combustors

The combustion chamber is of a loop counterflow axial design to minimise its length. It comprises sixteen combustors wherein duplex fuel nozzles are installed.

Two plasma-jet fuel ignitors are incorporated in the combustion chamber. Each ignitor comprises a fuel nozzle and a plasma-jet plug powered by a starting power supply unit.

### 3.5. GTE Cooling

The high-temperature section of GTE is externally-forced-air-cooled.

Rotor and stator blades of all three turbines of the GTE are air-cooled to achieve its long Mean Time Before Half-Overhaul (the 25,000 firing hours quoted value and the 37,000 firing hours practical value).

To provide most effective air-cooling, rotor and stator blades of all three turbines of the GTE have unique passage bifurcate internal channels.

The gas temperature at the high-pressure turbine outlet is monitored apart from exhaust gas temperature.

### 3.6. Coating of Blades of Turbines

#### 3.6.1. High-Pressure Turbine

**INNER CHANNELS** of **STATOR and ROTOR** blades are coated from inside with the Co-Cr-Al heat-shielding and corrosion-resistant material that is vacuum-evaporated-and-deposited.

**EXTERNAL SURFACE** of **ROTOR** blades of is coated by three layers: the Co-Cr-Al base, the Co-Cr-Al-Y middle layer and the zirconium-oxide/yttrium oxide outer coat. The coating is made by pulsed plasma in dynamic vacuum.

**EXTERNAL SURFACE** of **STATOR** blades are coated with two layers of Co-Cr-Al-Y and one layer of the zirconium-oxide/yttrium oxide outer coat. The coating is made by pulsed plasma in dynamic vacuum.

#### 3.6.2. Low-Pressure Turbine and Power Turbine

**INNER CHANNELS** of **STATOR and ROTOR** blades are non-coated.

**EXTERNAL SURFACE** of **STATOR and ROTOR** blades is coated with Niobium-Silicon-Aluminium coating.
3.7. **Lubrication**

All rotor- and auxiliary equipment bearings are circulated force lubricated. The lub oil is supplied from the oil pump that is brought into operation by the rotor of low-pressure turbocompressor.

In addition, GTE is equipped with AC electric motor driven oil pumps for boosting and scavenging oil. These pumps operate during GTE startup and shutdown.

Each rotating support is oil-scavenged individually, with independent monitoring and alarming of oil temperature and absence of chips in oil.

3.8. **Alternator and starters**

The power turbine is connected to an alternator via compensating elastic coupling of a diaphragm type and torque-limiting coupling to protect power turbine rotor against short-circuit mechanical shocks.

The power turbine is equipped with its own independent over-speed protection system, other than that of GTE Control System.

GTE is started by motoring the rotor of the high-pressure turbo-compressor by a starting unit. The starting unit comprises three AC electric starters.

3.9. **Monitored Parameters**

The following magnitudes are monitored during EGT running:

- RPM of each of three rotors,
- Gas temperature at high-pressure turbine,
- Exhaust gases temperature,
- Operation of fuel nozzles and combustors,
- Multi-point vibration level measurement,
- Temperature and pressure of oil drained out of each rotor support,
- Chip detection in oil drained out of each rotor support.

Eighteen hatchways are provided for internal visual inspection of combustors, fuel nozzles, blades of compressor and turbines, by borescope. Manual rotation of each rotor is available during inspection.
4. MAIN SPECIFICATIONS

1. Rated shaft power, MW 16.3
2. Peak shaft power, MW 18.0
3. Efficiency at rated shaft power 30.5
4. Efficiency at peak shaft power 31.0
5. Gas temperature at turbine inlet for rated power, °C 851
6. Gas temperature at turbine inlet for peak power, °C 883
7. Exhaust gas flow rate vs power Sec. 7, p. 16
8. Exhaust gas temperature vs power Sec. 8, p. 17
9. Efficiency vs power Sec. 9, p. 18
10. Shaft power vs inlet air temperature Sec. 12, p 21
11. Change in power, efficiency, exhaust gas flow rate and exhaust gas temperature:
   11.1. vs overall pressure losses in the intake air duct Sec. 12, p. 21
   11.2. vs overall pressure losses in the exhaust duct Sec. 13, p.22
12. Basic GTE parameters at ISO 2314 conditions Sec. 14, p. 23
13. Rotor turbine RPM 3,000
14. High-pressure turbo-compressor RPM, maximum 8,350
15. Low-pressure turbo-compressor RPM, maximum 6,900
16. Critical RPM of high-pressure turbo-compressor:
   16.1. first critical speed 15,850
17. Critical RPM of low-pressure turbo-compressor:
   17.1. first critical speed 3,000
   17.2. second critical speed 8,200
18. Critical RPM of the power turbine 7,780
19. Fuel system:
   19.1. Diesel fuel specifications Sec. 15, p. 24
   19.2. Diagram of fuel system with requirements to a Utility fuel system Sec. 16, p. 25
20. Lubrication system:
   20.1. Irretrievable lub oil losses, kg/hr 2
   20.2. Lub oil specifications Sec. 17, p. 28
   20.3. Diagram of lubrication system Sec. 18, p. 29
   20.4. Specifications for lubrication system diagram Sec.18.1, p. 30
   20.5. Requirements to a Utility oil system Sec.18.2, p. 33

21. Pneumatic system:
   21.1. Diagram of pneumatic control system Sec.19, p. 35
   21.2. Specifications for pneumatic system diagram Sec.20.1, p. 38
   21.3. Requirements to a Utility air system Sec.20.2, p. 39

22. Diagram of washing system Sec. 21, p. 40

23. GTE own electric power consumption Sec. 22, p. 43

24. Manoeuvrability factors:
   24.1. Time of starting-up and to getting idle mode, min 5
   24.2. Time-span of GTE startup Sec. 23, p. 45
   24.3. Time of heating-up at idle mode, min 5
   24.4. Time of taking rated load after heating-up in idle mode, min 5
   24.5. Time of emergency taking rated load after getting idle mode without heating, min 3
   24.6. Time of rated unloading from MCR or peak mode to idle mode, min 2
   24.7. Time of emergency unloading from MCR or peak mode to idle mode, s 30
   24.8. Time of taking peak load after heating up and operating at MCR not less than 20 min, s 10
   24.9. Time of cooling in idle mode after rated unloading, min 15

25. Durability factors
   25.1. Number of startups and shutdowns no restrictions
   25.2. Time before replacement 32,000 - 60,000 depending on operating conditions; no replacements of parts before
of combustors, hour

25.3. Time before half-overhaul, hour
32,000 hours

25.4. Time before major overhaul, hour

25.5. Life expectancy, year
20

26. Warranty period, month

27. Noise level
Sec. 24, p. 46

28. GTE container overall dimensions drawing
Sec. 25, p. 48

29. Total weight of GTE with container, kg
18,200

30. GTE overall dimensions
Sec. 26, p. 50

31. Total weight of GTE without container, kg
16,000

32. Labour expenditures for technical service
Sec. 27, p. 51

33. Cooling of GTE container

34. Control system
Sec. 27

35. Delivery set
Sec. 29, p. 53

36. NO\textsubscript{X} emission, mg/nm\textsuperscript{3}

36.1. for gaseous fuel (15% O\textsubscript{2})
150\textsuperscript{1}

36.2. for diesel fuel
300

37. Decreasing in power before overhauls, % of MCR
5 (rel. %)

38. Decreasing in efficiency before overhauls, % of initial efficiency
3 (rel. %)

\textsuperscript{1} Can be reduced to 50 mg/nm\textsuperscript{3} if optional steam injection apparatus is used.
5. GENERAL VIEW
6. LONGITUDINAL SECTION

Figure 1. Longitudinal section of GT16000 Gas Turbine Engine
7. **EXHAUST GAS FLOW RATE vs SHAFT POWER**

![Graph showing exhaust gas flow rate vs shaft power in ISO 2314 conditions.](image)

*Figure 2. GT16000 exhaust gas flow rate vs shaft power in ISO 2314 conditions*
8. **EXHAUST GAS TEMPERATURE vs SHAFT POWER**

![Graph showing the relationship between exhaust gas temperature and shaft power for the GT16000 gas turbine engine.]

Figure 3. GT16000 exhaust gas temperature vs shaft power in ISO 2314 conditions.
9. EFFICIENCY vs SHAFT POWER

Figure 4. GT16000 efficiency vs shaft power in ISO 2314 conditions
10. **FUEL CONSUMPTION vs SHAFT POWER**

![Graph showing fuel consumption vs shaft power](image)

Figure 5. GT16000 Standard Fuel flow rate vs shaft power in ISO 2314 conditions. (Fuel Net Calorific Value NCV = 42 MJ/kg)
11. DE-RATING vs INLET AIR TEMPERATURE

![Graph showing reducing of GT16000 output vs inlet air temperature at sea level.]

Figure 6. Reducing of GT16000 output vs inlet air temperature at sea level
12. INTAKE AIR DUCT LOSSES

Given below are changes in shaft power, efficiency, exhaust gas flow rate and exhaust gas temperature vs overall pressure losses in the intake air duct.

The values are given in relative percent.

![Figure 7. Reducing of GT16000 performances vs intake air duct losses in ISO 2314 conditions](image)
13. EXHAUST DUCT LOSSES

Given below are changes in shaft power, efficiency, exhaust gas flow rate and gas temperature at the outlet vs overall pressure losses in the exhaust duct. The values are given in relative percent.

![Graph showing changes in exhaust performance](image)

**Figure 8. Reducing of GT16000 performances vs exhaust duct losses in ISO 2314 conditions**
### 14. BASIC PARAMETERS AT ISO 2314 CONDITIONS

Table 1

<table>
<thead>
<tr>
<th>Operation mode</th>
<th>Shaft power MW</th>
<th>Compression ratio a.u.</th>
<th>Inlet air flow rate kg/s</th>
<th>Turbine inlet temperature °C</th>
<th>Exhaust gas temperature °C</th>
<th>Heat rate, MJ/kW·hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>18,000</td>
<td>13.1</td>
<td>100.0</td>
<td>883</td>
<td>362</td>
<td>11.610</td>
</tr>
<tr>
<td>MCR</td>
<td>16,300</td>
<td>12.6</td>
<td>92.0</td>
<td>851</td>
<td>350</td>
<td>11.650</td>
</tr>
<tr>
<td>75% MCR</td>
<td>12,230</td>
<td>10.9</td>
<td>88.0</td>
<td>760</td>
<td>314</td>
<td>12.120</td>
</tr>
<tr>
<td>50% MCR</td>
<td>8,150</td>
<td>9.1</td>
<td>77.5</td>
<td>665</td>
<td>281</td>
<td>13.530</td>
</tr>
<tr>
<td>25% MCR</td>
<td>4,075</td>
<td>7.2</td>
<td>64.0</td>
<td>575</td>
<td>252</td>
<td>18.750</td>
</tr>
</tbody>
</table>
15. DIESEL FUEL SPECIFICATIONS*

1. Flash point CC, °C 35 to 62
2. Pour point, °C -10 to -55
3. Cloud point, °C -10 to -35
4. Ash content, up to, % 0.01
5. Conradson carbon residue 10% bottom, not more than, % 0.3
6. Mechanical impurities content 0
7. Hydrogen sulphide content 0
8. Water content 0
9. Kinematics viscosity at 20°C, cSt 1.5 to 6.0
10. Sulphur content, not more than, % 0.5
11. Mercaptan sulphur content, not more than, % 0.01
12. Water-soluble acids and alkalis content 0
13. Iodine number, not more than, g iodine per 100 g of fuel 6
14. Density at 20°C, kg/m³ 830 to 860
15. Acid number, not more than, mg KOH per 100 cm³ of fuel 5

* DIESEL FUEL ANALOGUES: F-54 (NATO), Onorm C1104 (Austria), E/C-1055 (Italy), MIL-F 16844F Amd.2 (USA), VTL-9140-001 Iss.3 (Germany), DCES-21C Ed.1 Amd.1 (France), YIS K 2204 Type 2 (Japan)
16. FUEL SYSTEM

![Schematic Diagram of GT16000 Engine fuel system](image)

**Figure 9. Schematic Diagram of GT16000 Engine fuel system (solid lines — GT16000 pipelines, dash lines — Utility pipelines)**
### 16.1. Fuel system specifications

#### Table 2

<table>
<thead>
<tr>
<th>Designation</th>
<th>Name</th>
<th>Number</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>ÁDÉ</td>
<td>Assembly of distribution valves</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Å</td>
<td>Throttle</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ÅÄ1-ÅÄ2</td>
<td>“Sapphire” high-precise pressure sensor, output signal 4...20 mA, scale 0..0.6 MPa</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>ÅÄ3-ÅÄ5</td>
<td>“Sapphire” high-precise pressure sensor, output signal 4...20 mA, scale 0...10 MPa</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>ÅÅî</td>
<td>Dry contact sensor of pressure, setting $P&gt;0.1$ MPa</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ÅÄ</td>
<td>Dry contact sensor of pressure difference, setting $\Delta P&lt;1.2$ kgf/cm$^2$</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>ÉÅÑ</td>
<td>Emergency scavenging valve 074088006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ÉÅ</td>
<td>Drain valve A90088018</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ŕ</td>
<td>Reverse valve 090518001</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ŕ</td>
<td>Steady drop valve K49088000</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ÈÄ</td>
<td>Governing valve of control system</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ÈÄ</td>
<td>Solenoid valve 1ÊÔ-176</td>
<td>1</td>
<td>starting fuel</td>
</tr>
<tr>
<td>ë</td>
<td>Gear electric pump Ä59088017-01</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ÑÄ1</td>
<td>Pressure indicator, signal at 0.45 MPa</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ÑÄ3</td>
<td>Pressure indicator, signal at 0.1 MPa</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ÑÈ</td>
<td>Shut-down solenoid valve 075088022</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ô1</td>
<td>Fuel filter 012088010-05</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ô2</td>
<td>Filter P76088040</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
16.2. Requirements to a Utility fuel system:

1. Fuel preparation system must provide the following parameters at the input of the GT16000 fuel system (fuel filter inlet):
   - pressure – 0.18…0.3 MPa
   - temperature – 10…40 °C
   - removal of mechanical impurities – up to 20 µ
   - consumption, max – not more than 5000 kg/hr

2. Venting tanks must be located 0.5 m below the engine frame

3. Fuel preparation system must be equipped with a booster pump of 7000 kg/hr rate, pressure controller and filter.

4. Parts of fuel preparation system are preserved by gas turbine oil of not more than 10 cSt viscosity with no water content.
## 17. LUBE OIL SPECIFICATIONS

### Table 3

<table>
<thead>
<tr>
<th>Specification</th>
<th>MS8p</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Kinematics viscosity, cSt</td>
<td></td>
</tr>
<tr>
<td>at +50°C</td>
<td>8.0</td>
</tr>
<tr>
<td>at +20°C</td>
<td></td>
</tr>
<tr>
<td>at –40°C</td>
<td>4000</td>
</tr>
<tr>
<td>2. Viscosity indicator</td>
<td>-</td>
</tr>
<tr>
<td>3. Acid number, not more than, mg of KOH per 1 g of oil,</td>
<td>0.05</td>
</tr>
<tr>
<td>4. Ash content, %</td>
<td>0.008</td>
</tr>
<tr>
<td>5. Pour point, °C</td>
<td>-55</td>
</tr>
<tr>
<td>6. Cloud point, °C</td>
<td>-10 to -35</td>
</tr>
<tr>
<td>7. Stability against oxidation:</td>
<td></td>
</tr>
<tr>
<td>residue after oxidation, not more than, %</td>
<td>0.15</td>
</tr>
<tr>
<td>acid number of oxidised oil, not more than, mg of KOH per 1 g of oil,</td>
<td>0.70</td>
</tr>
<tr>
<td>8. Water-soluble acids and alkalis content</td>
<td>0</td>
</tr>
<tr>
<td>9. Mechanical impurities content</td>
<td>0</td>
</tr>
<tr>
<td>10. Water content</td>
<td>0</td>
</tr>
<tr>
<td>11. Flash point determined in a closed crucible, °C</td>
<td>150</td>
</tr>
<tr>
<td>12. Density at 20°C, kg/cm3</td>
<td>0.875</td>
</tr>
</tbody>
</table>

* LUBE OIL ANALOGUES: Aero Shell Turbine Oil 3P, Aero Shell Turbine Oil 3, Castrol Aero 1010, Mobil Avrexm Turbo 201/1010. Other lube oils may be used after a Manufacturer approval on the basis of investigation of their physical-chemical characteristics
18. LUBRICATION SYSTEM

Figure 10. Schematic Diagram of GT16000 Engine lube oil system
### 18.1. **Lubrication system specifications**

**Table 4**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Designation</th>
<th>Name</th>
<th>Number</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB</td>
<td>LM04</td>
<td>Boostering oil unit with DC electric drive</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>LM05</td>
<td>Scavenging oil unit with DC electric drive</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5A</td>
<td>LP070</td>
<td>Pressure indicator MCTB-0.2A</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>6A</td>
<td>LP080</td>
<td>Pressure indicator MCTB-2.5A</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7A</td>
<td>LP090</td>
<td>Pressure indicator MCTB-0.4A</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indicator-Relay of difference in pressure DEM 202-1-01A</td>
<td></td>
<td>Adjustment for 8.15 MPa</td>
</tr>
<tr>
<td>7B</td>
<td>LP100</td>
<td>Pressure drop on Ø1, Ø2 filters</td>
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<td>Pressure indicator MCTB-0.2A</td>
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<td>Magnetic chip detector A59078010:</td>
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<td>7A</td>
<td>LS010</td>
<td>at draining out of lower drive box</td>
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<td>6B</td>
<td>LS020</td>
<td>at draining out of the adaptor</td>
<td></td>
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<td>5B</td>
<td>LS030</td>
<td>at draining out of rear casing of high-pressure compressor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5B</td>
<td>LS040</td>
<td>at draining out of supporting rim of low-pressure turbine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5B</td>
<td>LS050</td>
<td>at draining out of supporting rim of high-pressure turbine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7B</td>
<td>LS060</td>
<td>at draining out of main drive support</td>
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<td>5A</td>
<td>LT010</td>
<td>at the GTE inlet (in the tank)</td>
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<tr>
<td>Zone</td>
<td>Designation</td>
<td>Name</td>
<td>Number</td>
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<td>-------------</td>
<td>-------------------------------------------------------------</td>
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<td>LT020</td>
<td>at draining out of the adapter</td>
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<tr>
<td>5B</td>
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<td>at draining out of rear casing of high-pressure compressor</td>
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<td></td>
</tr>
<tr>
<td>5B</td>
<td>LT040</td>
<td>at draining out of supporting rim of low-pressure turbine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5B</td>
<td>LT050</td>
<td>at draining out of supporting rim of high-pressure turbine</td>
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<td></td>
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<tr>
<td>BB</td>
<td>LT060</td>
<td>at the GTE outlet (in the scavenging line)</td>
<td></td>
<td>in the set</td>
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<tr>
<td>6B</td>
<td>I</td>
<td>Connection M16x1.5 for monitoring oil in ÁÌ1</td>
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<td>6B</td>
<td>II</td>
<td>Connection M24x1.5 for feeding oil for preserving the fuel unit</td>
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<td>DÔ1</td>
<td>Level indicator C90078011-02</td>
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<td>7A</td>
<td>LL010</td>
<td>Indicator of minimum level</td>
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<td>Indicator of maximum level</td>
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<td>7A</td>
<td>LL030</td>
<td>Indicator of emergency level</td>
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<td>AT1</td>
<td>Unit for oil air cooling</td>
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<td>Á1</td>
<td>Circulated tank</td>
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<td>8A</td>
<td>Á11, Á12</td>
<td>Receiving gauze, cell size of 2.5 mm</td>
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<td>5B</td>
<td>ÁM1</td>
<td>Tank for oil separation</td>
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<tr>
<td>BB</td>
<td>ÄÐ1</td>
<td>Throttle washer of 1.5 mm diameter</td>
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<td></td>
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<tr>
<td>8A</td>
<td>K1</td>
<td>Shut valve of connection type 521-01.471-02</td>
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<td>D15</td>
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<td>8A</td>
<td>K2</td>
<td>Shut valve D15</td>
<td>1</td>
<td>facility</td>
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<tr>
<td>7B</td>
<td>MH1</td>
<td>Pressure gauge 1MPa, 2.5 accuracy</td>
<td>1</td>
<td>facility</td>
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<tr>
<td>8A</td>
<td>K01</td>
<td>Reverse valve 080078003</td>
<td>1</td>
<td>D70</td>
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<td>7B</td>
<td>K02</td>
<td>Reverse valve 080078004</td>
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<td>D50</td>
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<td>H1</td>
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<td>ÐÌÄ</td>
<td>Controller of pressure difference A80088020</td>
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<td>Static oil separator 080078010</td>
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<td>Filter 049078003-04</td>
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<td>filtr. degree 0.01 mm</td>
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<td>Filter T71078020</td>
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<td>filtr. degree 0.01 mm</td>
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<td>PT1</td>
<td>Temperature controller ÐÖÎ 65-45-1Ì</td>
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<td>facility</td>
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<td>7A</td>
<td>LEO1</td>
<td>Oil heater ÓÝÍ Á-10È220-È1 ÓÔÊÇ</td>
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<tr>
<td>8A</td>
<td>LH01... LH03</td>
<td>Automatic valve 005078010</td>
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<td>5A</td>
<td>LH04</td>
<td>Shut-down valve 005078005</td>
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<td>LM01</td>
<td>Boostering oil unit with electric drive K58078010-01</td>
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<td>LM02</td>
<td>Scavenging oil unit with electric drive 080078018</td>
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<tr>
<td>8A</td>
<td>LM03</td>
<td>Oil unit with electric drive 062078001</td>
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<td>Pressure sensor MT100P-11029-02-0.5-1 MPa-42-Ô2-H1</td>
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<td>7A</td>
<td>LP010</td>
<td>Pressure measurement point at the engine inlet</td>
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<tr>
<td>8A</td>
<td>LP020</td>
<td>Pressure measurement point at the scavenging line</td>
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<tr>
<td>7B</td>
<td>LP050</td>
<td>Pressure monitor MCTB-1A</td>
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<td></td>
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<td>7B</td>
<td>LP060</td>
<td>Pressure monitor MCTB-2A</td>
<td>1</td>
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</tr>
</tbody>
</table>
18.2. Requirements to a Utility oil system

1. Applicable oils are listed in Section 17.
2. Maximum operating pressure:
   2.1. in boosting pipelines – 0.7 MPa
   2.2. in scavenging pipelines – 0.25 MPa
   2.3. in scavenging, draining and breathing pipelines of the oil separation tank – 0.3 MPa
3. Temperature of engine oil:
   3.1. Main – at inlet: 40...50 °C
       – at startup: not less than 35 °C
   3.2. Back-up – at inlet: 30...50 °C
       – at startup: 15...50 °C
   3.3. At engine outlet: not more than 120 °C
4. Oil quantity for external drive box filling – 14 litre. The oil is required to be exchanged once a year.
5. Requirements to a circulated tank:
   5.1. Circulated tank and pipe lines are made of corrosion resistant materials;
   5.2. Recommended circulated tank capacity, not less then – 1.5 m³
   5.3. Oil quantity:
       minimum – 600 litre
       maximum – 900 litre
       emergency – 1000 litre
   5.4. Oil level above the cross-section of sucking pipelines, not less than – 0.1 m
6. Distance from the bottom of circulated tank to sucking pipelines, not less than – 0.05 m
7. Minimum oil level in the circulated tank is not less than 2.0 m from the engine axis.
8. Maximum oil level in the circulated tank is not less than 0.5 m below the engine axis.
9. Oil cooler AT1 is chosen on the basis of maximum oil pumping capacity of 4.17 kg/s (15000 kg/hr), heat taking off not less than 500 kW and the pressure indicated in item 3.2.

10. Hydraulic resistance of a facility pipeline should be not more than 0.25MPa at maximum pumping capacity and kinematic viscosity of main and spare oil grade of 40 cSt.

11. If oil cooler capacity is more than 500 litre, then draining off should be provided for oil cooler into oil unit KC when discharging AT1.

12. The air draining pipe out of the static oil cooler should be cut in just after cross section of the ejecting nozzle, at 45° angle along the gas flow. Four smooth turns with the turning angle of not more than 90° are permitted on the pipe. The pipe should have a rise without a slope.

13. KO1 valve should be located at ≤ 0.5 m distance from the Á1 tank.

14. Oil for filling the circulated tank should:
   • meet the technical specification,
   • have a temperature not less than 15 °C,
   • have a filtration degree not worse than 0.025 mm
19. ALTERNATOR

1. Type .................................................................................................................. C1018-1201-01
2. Applicable standards .................................................................. BS4999, BS5000:P2, IEC34-3
....................................................................................................................... IEC54-3; IEC34-1
3. Poles arrangement ...................................................................................................... non-salient
4. Number of poles ....................................................................................................................... 2
5. Maximum continuous rating, MW ................................................................................. 16
6. Rated power factor, a.u. ............................................................................................... 0.8
7. Voltage, kV ............................................................................................................. 11 at 50 Hz; 13.8 at 60 Hz
8. Speed, rpm ........................................................................................................... 3,000
9. Enclosure .................................................................................................................. IP 54 ICW37A81 (totally enclosed air-to-water-to-air cooled)
10. Stator insulation system ............................................................................................. Class F
11. Rotor insulation system ............................................................................................. Class F
12. Class F total temperatures:
   12.1. Maximum Stator operating temperature, °C ......................................................... 140
   12.2. Maximum Field operating temperature, °C ......................................................... 145
   12.3. Maximum Water inlet temperature, °C ................................................................. 32
13. Overspeed, rpm ........................................................................................................... 3,600
14. Efficiency, %
   at 100% MCR ........................................................................................................ 97.1
   at 75% MCR .......................................................................................................... 96.5
   at 50% MCR ........................................................................................................ 95.4
   at 25% MCR ........................................................................................................ 91.8
15. Direct-axis synchronous reactance $X_d$, Ohm ...................................................... 13.0
16. Direct-axis transient reactance $X'_d$, per unit .................................................. 0.15
17. Direct-axis sub-transient reactance $X''_d$, per unit ........................................... 0.095
18. Negative phase sequence reactance $X_n$, per unit ........................................... 0.116
19. Zero phase sequence reactance $X_0$, per unit ................................................... 0.0164
20. Transient field time constant:
   open-circuit $T'_{do}$, sec ........................................................................................................ 7.5
   short-circuit $T'_{ds}$, sec .................................................................................................. 0.59

21. Transient field time constant:
   open-circuit $T''_{do}$, sec .................................................................................................. 0.035
   short-circuit $T''_{ds}$, sec .............................................................................................. 0.074

22. Armature DC time constant $T_a$, sec ............................................................................. 0.2

23. Short-circuit ratio ........................................................................................................... 0.586

24. Torque at sudden 3-phase short circuit, N·m ................................................................... 554,000

25. Rotor inertia, kg·m² ......................................................................................................... 650

26. Bearing oil flow rate (per bearing), litre/min ................................................................... 36.7

27. Cooling water flow rate (per machine), litre/sec ............................................................... 25
20. PNEUMATIC SYSTEM

Figure 11. Schematic Diagram of GT16000 Engine pneumatic system
20.1. Pneumatic system diagram specifications

Table 5

<table>
<thead>
<tr>
<th>Designation</th>
<th>Name</th>
<th>Number</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>BA</td>
<td>Air cylinder B71518001</td>
<td>1</td>
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</tr>
<tr>
<td>BOO</td>
<td>Refining and cooling unit P76018095</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Metallic end cup for a drainage connection M16x1.5</td>
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</tr>
<tr>
<td>Œ Œ</td>
<td>Fuel manifold</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>KO</td>
<td>Reverse valve K71518003</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Œ Î D1...Œ Î D4</td>
<td>Air bleed valve Ā90038001</td>
<td>4</td>
<td>built in the engine frame</td>
</tr>
<tr>
<td>PH01...PH03</td>
<td>Electromagnetic air valve 25MA</td>
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<tr>
<td>PP010</td>
<td>Pressure sensor</td>
<td>1</td>
<td>is not included into the set of delivery</td>
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</table>

Table 6

<table>
<thead>
<tr>
<th>Name of a procedure</th>
<th>Air consumption per a procedure, nm³</th>
<th>Duration of air supplying, s</th>
</tr>
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<tbody>
<tr>
<td>Air supplying into a second channel of nozzles at startup</td>
<td>0.9</td>
<td>45</td>
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</tbody>
</table>

nm³ is normal cubic metre of free air equalled to m³ at 760 mm Hg (0.1 MPa) and 0°C
20.2. Requirements to a Utility air system

1. Air supplying in a Utility, should be dried up to the dew point minus 15 °C and purified with a filtration degree not worse than 50µ.

2. All units should be located in the area with temperature not more than 80 °C.

3. Air pipes for the fuel manifold should be installed in its upper part.

4. Air cylinder should be installed as close as possible to the valves ÊÍD1...ÊÍD4 with the neck located down to provide access for servicing.

5. Increasing of i.d.’s of pipe lines is tolerated.

6. The distance L is not more than 3m.
21. GTE WASHING

- Mixing device
- Level indicator
- Charging with washing solution
- Bleeding valve
- Compressed Air
- Fresh water pipeline
- To another engine
### 21.1. GTE washing diagram specifications

Table 7

<table>
<thead>
<tr>
<th>Designation</th>
<th>Name</th>
<th>Number</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Á1</td>
<td>Tank</td>
<td>1</td>
<td>200 litre volume</td>
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<tr>
<td>Á2</td>
<td>Tank</td>
<td>1</td>
<td>20 litre volume</td>
</tr>
<tr>
<td>BH1</td>
<td>Shut valve</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Ā1</td>
<td>Engine</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>ĖĒ1</td>
<td>Washing manifold</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>MH1</td>
<td>Pressure gauge</td>
<td>2</td>
<td>Local measurement</td>
</tr>
<tr>
<td>ľ 1</td>
<td>Electric heater</td>
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<td></td>
</tr>
<tr>
<td>TP1</td>
<td>Thermometer</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ŷ1</td>
<td>Filter, filtering degree 100 μ, resistance 0.1 MPa</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Connections for manifolds M27×1.5</td>
<td>2</td>
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</tr>
</tbody>
</table>
21.2. Requirements to an external washing system

1. Pressure of washing solution at the manifold inlet: ±0.2 MPa, temperature: 20...40 °C.

2. One engine washing requires 400 litre of fresh water, 12 litre of detergent, 80 litre of washing solution (68 litre of water and 12 litre of detergent), pressurised water 1.0±0.2 MPa, water consumption 3.0 m³.

3. Pressure of fresh water: 0.4±0.1 MPa, temperature: 20...40 °C.

4. Material of tanks, pipe lines and hardware for washing solution supplying should be corrosion resistant in water and alkaline medium.

5. Preparation of the washing solution and washing itself should be done in accordance with the Maintenance Manual.

6. Õõ1 manifolds are ended with the connections B.

7. One washing system can be used for several GTE.

8. GTE washing can be done by a mobile washing station. The respective scheme should be agreed with the Manufacturer if it is different from the shown scheme.

9. Normal air conditions are 760 mm Hg (0.1 MPa) and °C.

10. Washing detergent is Carbon Removal, Rochem Co.
### 22. GTE OWN ELECTRIC POWER CONSUMPTION

#### Table 8

<table>
<thead>
<tr>
<th>Unit</th>
<th>3~50 Hz 380 V</th>
<th>1~50 Hz 220 V</th>
<th>−110 V</th>
<th>−27V</th>
<th>Notes</th>
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<tbody>
<tr>
<td>1. Turbine</td>
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<td>1.1. Electric starters</td>
<td>420 kW in peak. 210 kW during 15 s</td>
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<td></td>
<td>at startup</td>
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<tr>
<td>1.2. Plasma-jet ignitors</td>
<td>6 kW</td>
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<td></td>
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<td>at startup</td>
</tr>
<tr>
<td>1.3. Temperature Controller</td>
<td></td>
<td></td>
<td>60 W</td>
<td></td>
<td>continuous during operation</td>
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<tr>
<td>1.4. Illumination of turbine container</td>
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<td></td>
<td>0.5 kW</td>
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<td>optional</td>
</tr>
<tr>
<td>1.5. Electric fans for turbine cooling</td>
<td>30 kW</td>
<td></td>
<td></td>
<td></td>
<td>continuous during GTE operation and after stop</td>
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<tr>
<td>2. Fuel system units</td>
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<tr>
<td>2.1. Fuel pump</td>
<td>30 kW</td>
<td></td>
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<td>2.2. Shut-down valve</td>
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<td>75 W</td>
<td></td>
<td>at startup and operation</td>
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<tr>
<td>2.3. Starting fuel and air valve</td>
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<td></td>
<td>80 W</td>
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<td>at startup and stop</td>
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<tr>
<td>2.4. Fuel draining valve</td>
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<td>40 W</td>
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<td>at operation of thermo-restriction system</td>
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<td>3. Lubrication system units</td>
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<td>3.1. Boostering pump</td>
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<td></td>
<td>at startup and up to 20%</td>
</tr>
<tr>
<td>Unit</td>
<td>3~50 Hz 380 V</td>
<td>1~50 Hz 220 V</td>
<td>–110 V</td>
<td>–27V</td>
<td>Notes</td>
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<tr>
<td>3.2. Boostering pump (reserve)</td>
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<td>2 kW</td>
<td>MCR at startup and up to 20% MCR</td>
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<td>3.3. Scavenging pump</td>
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<td>MCR at startup and up to 20% MCR</td>
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<td>3.4. Scavenging pump (reserve)</td>
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<td>2 kW</td>
<td>MCR at startup and up to 20% MCR</td>
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<td>3.5. Oil tank cleaning pump</td>
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<td>3.6. Oil heaters</td>
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<td>1.0 kW</td>
<td>1.0 kW</td>
<td>Optional</td>
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<td>4. Automatic control system</td>
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23. TIME-SPAN OF GTE STARTUP

Table 9

<table>
<thead>
<tr>
<th>Unit</th>
<th>Time, s</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ON</td>
</tr>
<tr>
<td>Electric starters</td>
<td>0</td>
</tr>
<tr>
<td>· first speed</td>
<td>0</td>
</tr>
<tr>
<td>· second speed</td>
<td>65</td>
</tr>
<tr>
<td>Ignition unit</td>
<td>85</td>
</tr>
<tr>
<td>Starting fuel valve</td>
<td>95</td>
</tr>
<tr>
<td>Starting air valve</td>
<td>100</td>
</tr>
<tr>
<td>Shut-down valve</td>
<td>100</td>
</tr>
</tbody>
</table>

from the “Stop” button or when protection tripping
24. NOISE LEVEL

24.1. Total noise level, dB

Table 10

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>At inlet</td>
<td>145</td>
</tr>
<tr>
<td>At outlet</td>
<td>142</td>
</tr>
<tr>
<td>Without container</td>
<td>135</td>
</tr>
<tr>
<td>With container</td>
<td>101</td>
</tr>
</tbody>
</table>

24.2. Octave noise level, dB

Table 11

<table>
<thead>
<tr>
<th>Octave Band Centre Frequency, Hz</th>
<th>31.5</th>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
</tr>
</thead>
<tbody>
<tr>
<td>At inlet</td>
<td>125</td>
<td>126</td>
<td>127</td>
<td>125</td>
<td>126</td>
<td>125</td>
<td>141</td>
<td>141</td>
<td>138</td>
</tr>
<tr>
<td>At outlet</td>
<td>136</td>
<td>137</td>
<td>140</td>
<td>140</td>
<td>139</td>
<td>136</td>
<td>135</td>
<td>134</td>
<td>129</td>
</tr>
<tr>
<td>Without container</td>
<td>112</td>
<td>114</td>
<td>120</td>
<td>124</td>
<td>122</td>
<td>124</td>
<td>127</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>With container</td>
<td>112</td>
<td>114</td>
<td>110</td>
<td>104</td>
<td>95</td>
<td>91</td>
<td>89</td>
<td>91</td>
<td>84</td>
</tr>
</tbody>
</table>
Figure 12. GT16000 Noise Spectrum measured at 1 metre distance
25. GTE INSTALLATION

Figure 13. GT16000 container overall dimensions (mm) and foundation anchor points
### 25.1. Foundation loading

<table>
<thead>
<tr>
<th>Load</th>
<th>GTE container</th>
<th>Oil unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$G_1(G_1')$</td>
<td>$G_2(G_2')$</td>
</tr>
<tr>
<td>Static component of weight, kg</td>
<td>1000</td>
<td>6650</td>
</tr>
<tr>
<td>Component of max. torque, kg</td>
<td>±2250</td>
<td>±4500</td>
</tr>
<tr>
<td>Variable component against vibration overloading, max. kg</td>
<td>2000</td>
<td>13300</td>
</tr>
<tr>
<td>Maximum value, kg</td>
<td>3000</td>
<td>22200</td>
</tr>
</tbody>
</table>
26. GTE OVERALL DRAWING

Figure 14. GT16000 overall dimensions, mm
27. **EXAMPLE OF MAINTENANCE SCHEDULE**

Labour expenditures for technical service of GTE integrated in a peak power plant

Example of peak power plant operation:

- operating hours per year – 2,000
- number of startups – 500
- operation mode – peak

On the basis of the example above there are following intervals and labour expenditures for GTE technical service. Total labour expenditures are 66 man-hours per year:

1. **Inspection and preventive service after 500 hours of GTE operation** (125 startups) or once in three months – 7 man-hours (28 man-hours per year).
   
   Scope of service:
   
   - visual inspection of major units and parts of GTE,
   - draining sludge from the oil tank, analysis of oil, inspection of oil and fuel filters, inspection of chip indicators,
   - inspection of electrical equipment and automatic control system.

2. **Inspection and preventive service after 1000 hours of GTE operation** (250 startups) or once in six months – 10 man-hours (20 man-hours per year).
   
   Scope of service:
   
   - inspection and testing of fuel system (throttle batch, throttle of starting fuel, filters of the automatic system).

3. **Inspection and preventive service after 2000 hours of GTE operation** (500 startups) or once a year – 18 man-hours.
   
   Scope of service:
   
   - inspection of GTE flowing part using borescopes,
   - inspection of oil filters,
   - testing of electric insulation resistance of electrical equipment,
   - inspection of fuel nozzles and clamping of combustors using borescopes,
   - testing of GTE-alternator balance,
   - cleaning of the oil tank,
   - washing of GTE compressor.
28. CONTROL SYSTEM

GTE Automatic Control System (ACS) may be supplied using a hardware and software of few reputable manufacturers.

A particular manufacturer of ACS components is chosen with participation of a Customer.

ACS may cover either GTE only or optionally comprise the following:

- alternator controls and alternator protections,
- control over a whole power plant,
- control of combined cycle units,
- remote control through high frequency or microwave channel,
- remote monitoring through internal modem.

One- or two-level standby reservations are another possible options for a ACS.

An example of acceptable ACS is Digicon hardware of Hawker Siddeley Dynamics Engineering company, UK.

The hardware is of the 50,000 hours of continuous operation Mean time before fault (design value).

The availability factor is 99.97% (if no control hardware redundancy).

The full-travel time of Digicon control fuel valve, both of gaseous- and liquid fuel version, is 100 ms. Its repeatability and hysteresis are better than 2% of full scale.
29. **DELIVERY SET**

1. GT16000 gas turbine engine (GTE)
2. Control System with control panel for GT16 Genset
3. Brushless alternator (11 kV, 50 Hz, Cos φ = 0.8) with its protections and AVR
4. GTE frame and acoustic enclosure
5. Exhaust adapter with exhaust duct and silencer
6. Resilient shaft with maximum torque coupling
7. Engine-Alternator coupling
8. Engine-to-Alternator gearbox
9. Electric fan for GTE cooling
10. GTE oil unit
11. Alternator oil unit
12. Complete oil cooling system
13. Unit for measuring engine and alternator vibration
14. Motor driven auxiliary and emergency pumps
15. Genset storage battery and charger
16. One diesel engine startup genset
17. **CO₂ Fire Protection System** for the turbine-accessories-gearbox compartment; the system comprising nozzles, detectors, wiring and interconnection pipes to CO₂ storage bottles
18. Set of walkways and steps surrounding the GT enclosure
19. Inlet air filter
20. Inlet ducting and silencing assemblage
21. Set of servicing and maintenance manuals in English language
22. Set of special maintenance tools and installation consumables
23. Supervision of installation and commission
24. Touch-up paint for site use