MASHPROEKT, Ukraine

FIZIKA Scientific, New Zealand

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 boostering 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
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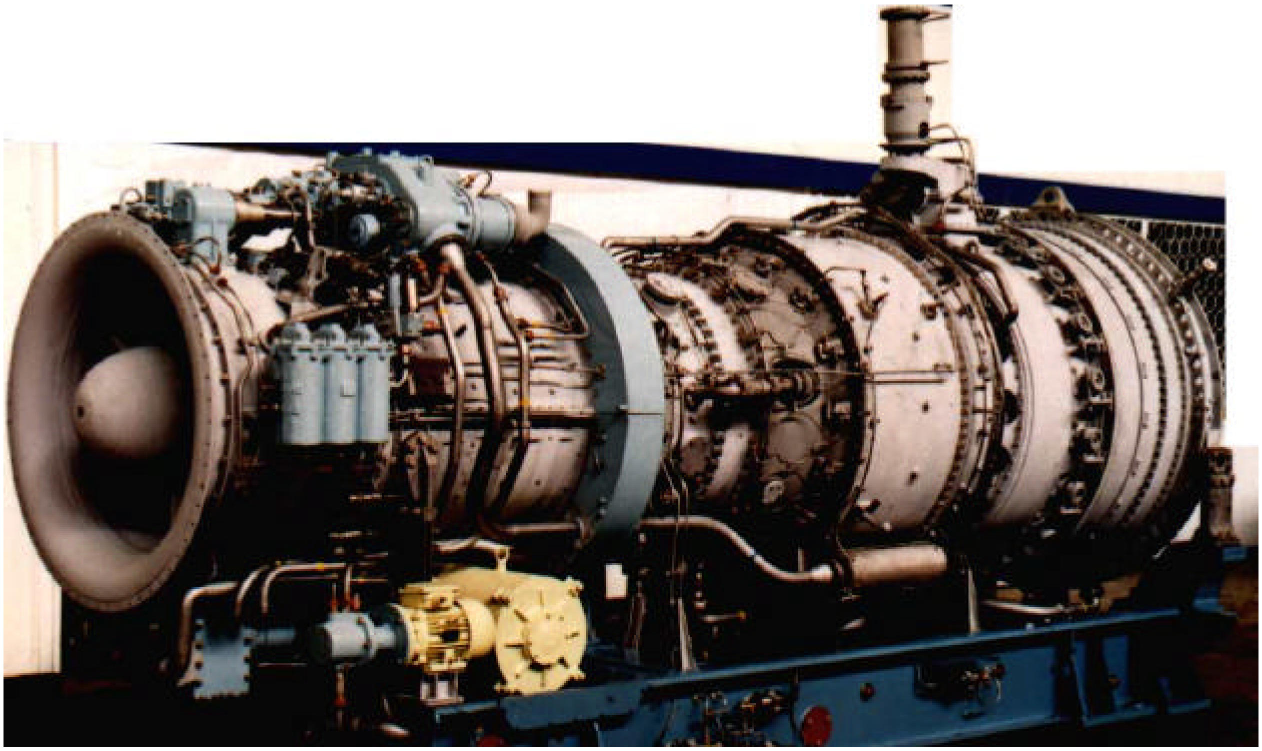
	24.5.	Time of emergency taking rated load after getting idle mode without heating, min	3
	24.6.	Time of rated unloading from MCR or peak mode to idle mode, min	2
	24.7.	Time of emergency unloading from MCR or peak mode to idle mode, s	30
	24.8.	Time of taking peak load after heating up and operating 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	32,000 hours
	25.3.	Time before half-overhaul, hour	32,000 extended to 40,000 or 60,000 upon inspection
	25.4.	Time before major overhaul, hour	50,000 extended to 67,000 upon inspection, depending on operating conditions
	25.5.	Life expectancy, year	20
26.	Warranty period, month		
		from the date of beginning of operation	12
		from the date of despatching	18
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		air
	Cooling air flow rate, kg/s		10
34.	Control system		Sec. 27
35.	Delivery set		Sec. 29, p. 53
36.	NO_X emission, mg/nm^3		
	36.1.	for gaseous fuel (15% O_2)	150[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. %)

[1] Can be reduced to 50 mg/nm^3 if optional steam injection apparatus is used.

5. GENERAL VIEW



6. LONGITUDINAL SECTION

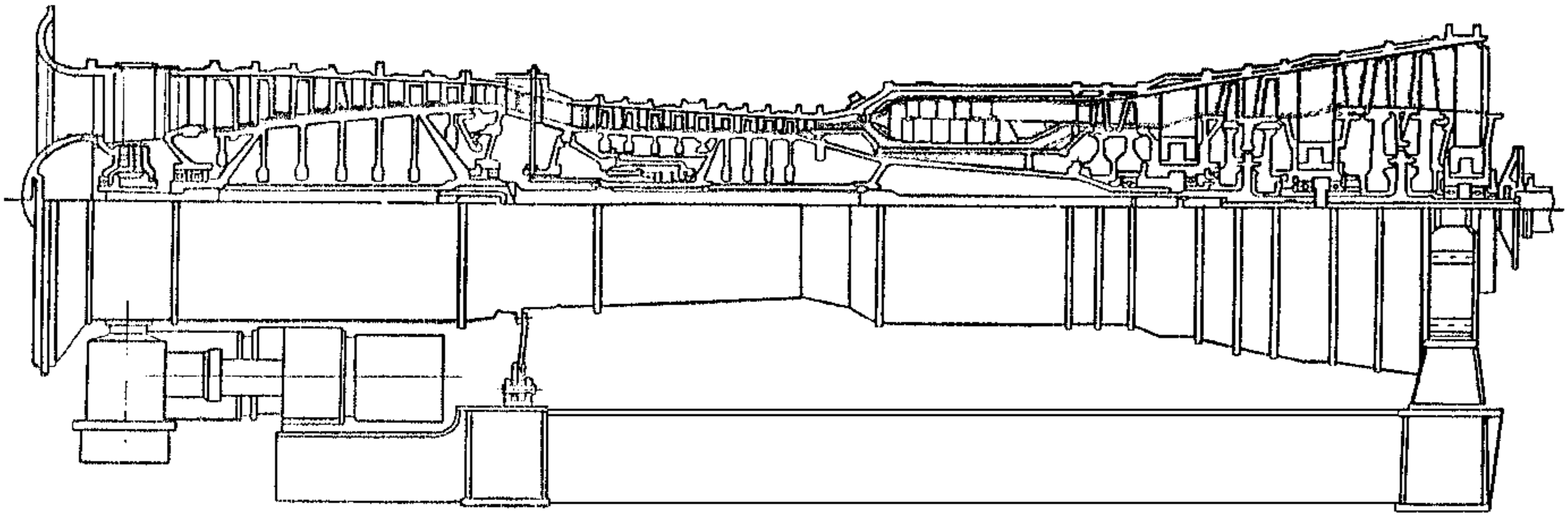


Figure 1. Longitudinal section of GT16000 Gas Turbine Engine

7. EXHAUST GAS FLOW RATE vs SHAFT POWER

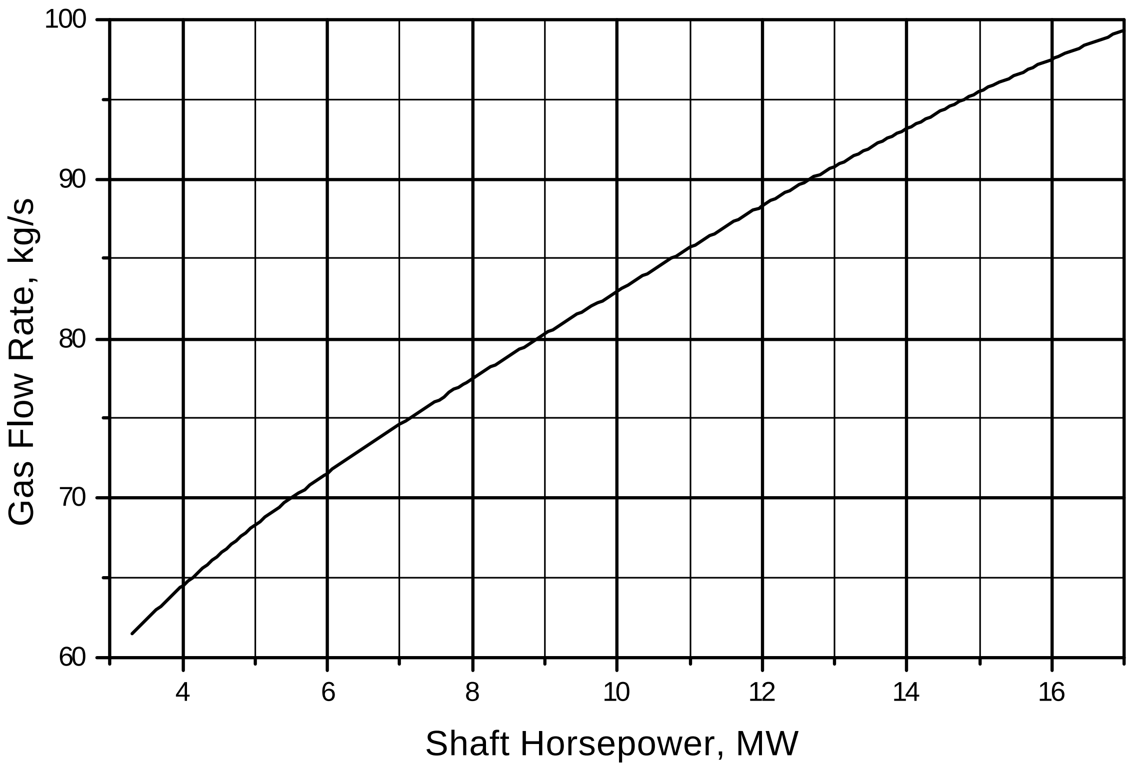


Figure 2. GT16000 exhaust gas flow rate vs shaft power in ISO 2314 conditions

8. EXHAUST GAS TEMPERATURE vs SHAFT POWER

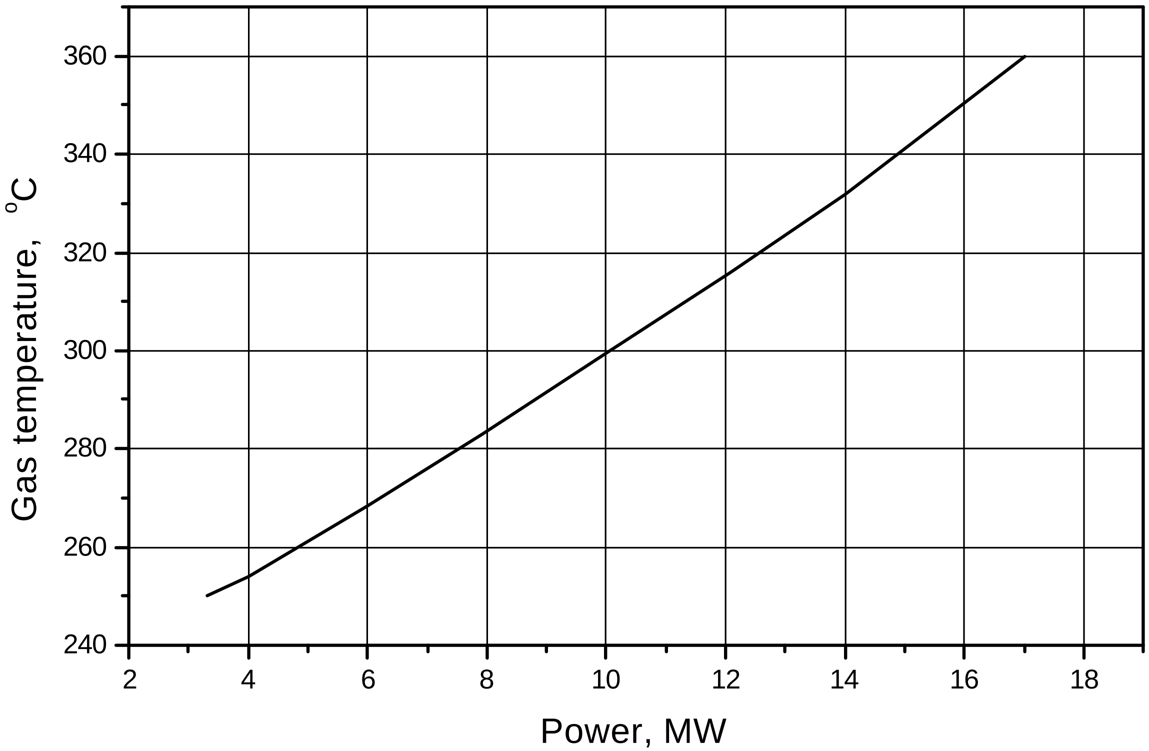


Figure 3. GT16000 exhaust gas temperature vs shaft power in ISO 2314 conditions

9. EFFICIENCY vs SHAFT POWER

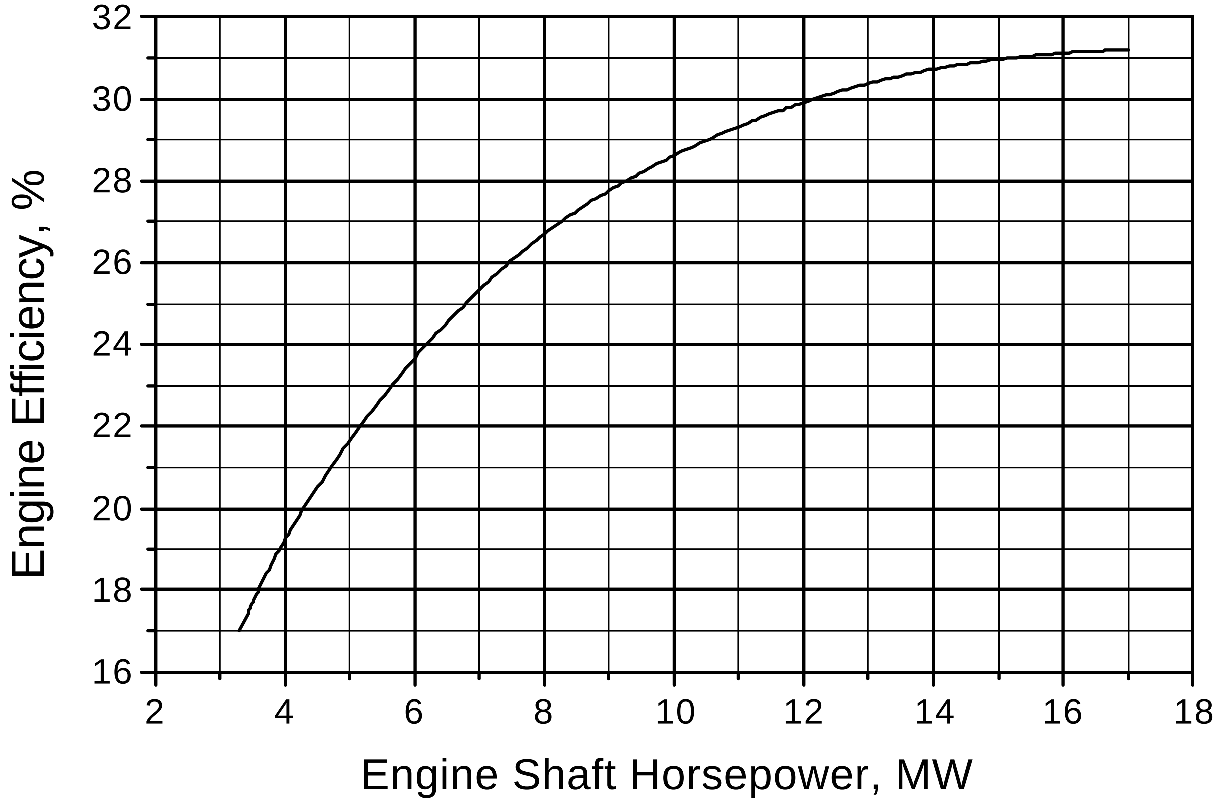


Figure 4. GT16000 efficiency vs shaft power in ISO 2314 conditions

10. FUEL CONSUMPTION vs SHAFT POWER

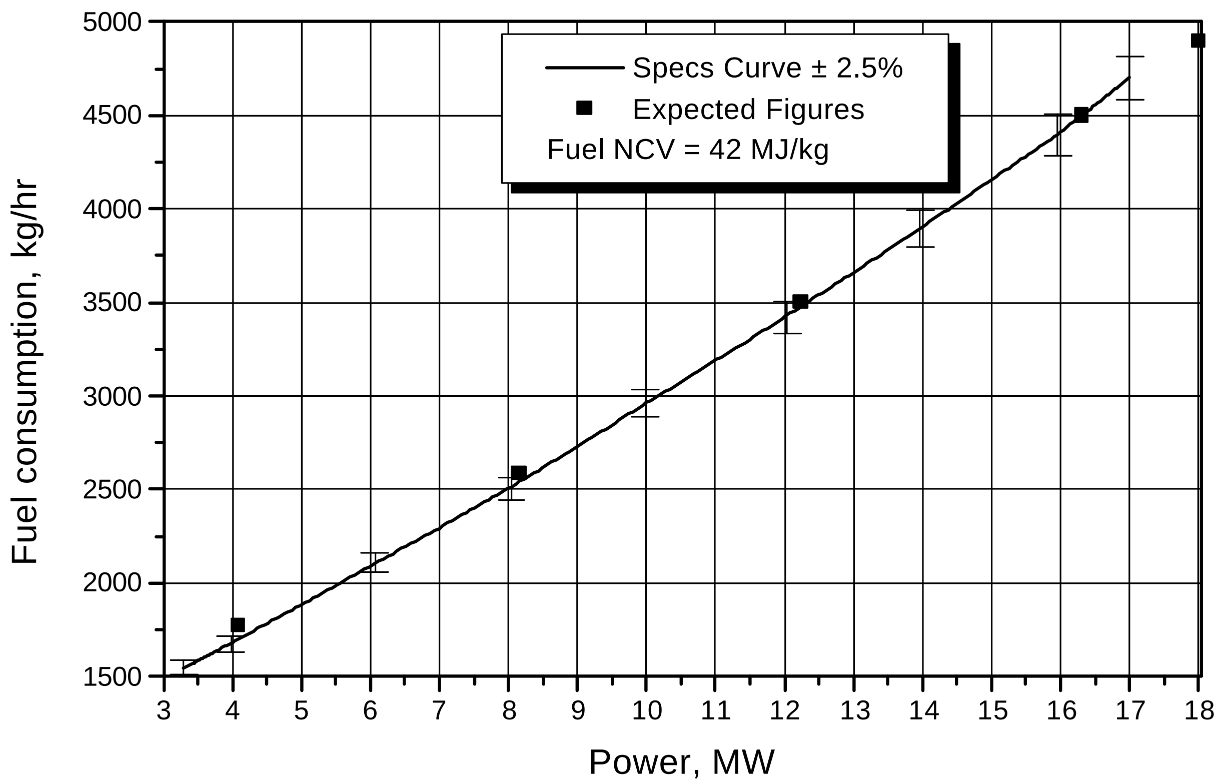


Figure 5. GT16000 Standard Fuel flow rate vs shaft power in ISO 2314 conditions. (Fuel Net Calorific Value NCV =42 MJ/kg)

11. DE-RATING vs INLET AIR TEMPERATURE

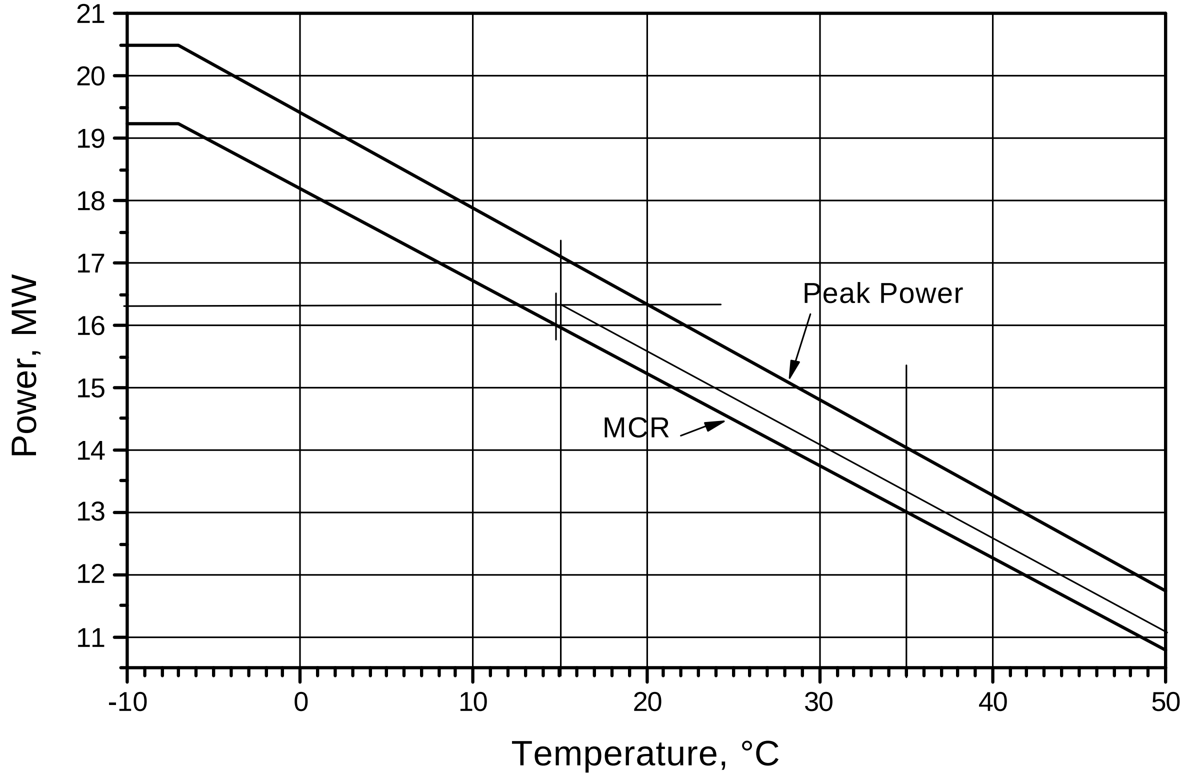


Figure 6. Reducing of GT16000 output vs inlet air temperature at sea level

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.

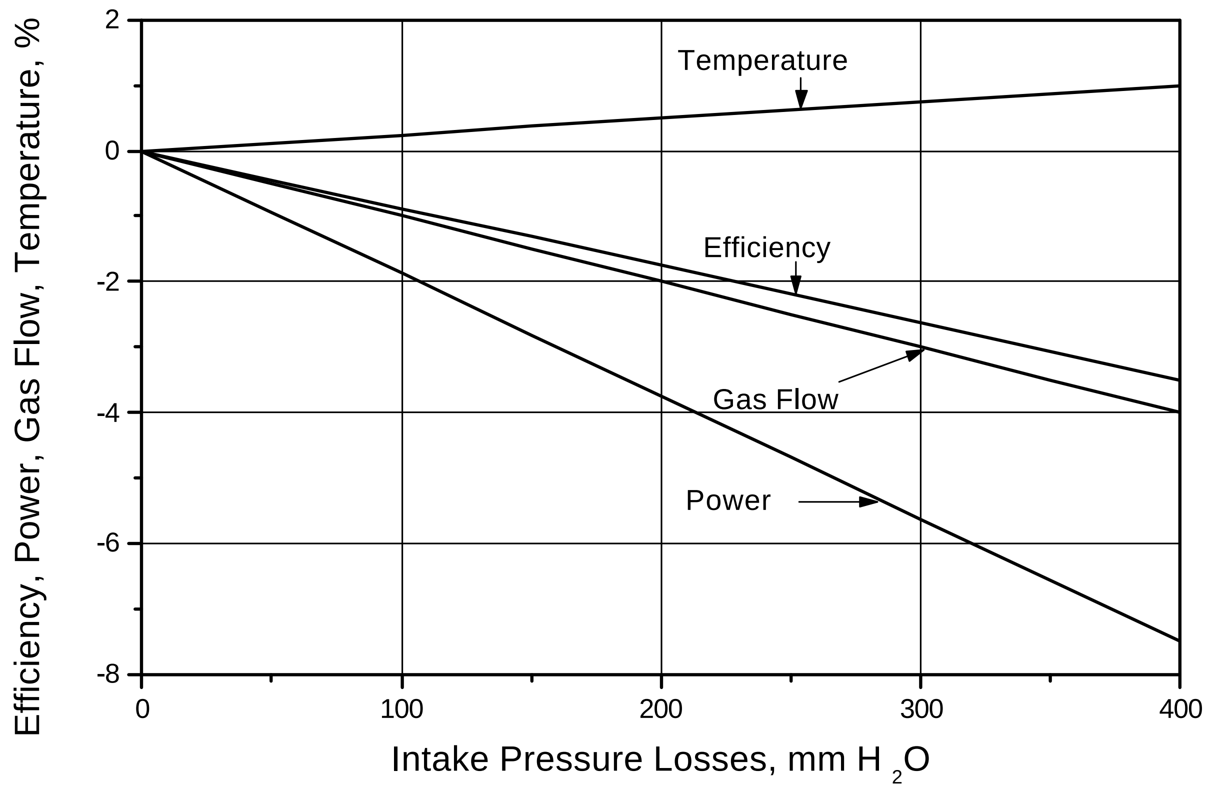


Figure 7. Reducing of GT16000 performances vs intake air duct losses in ISO 2314 conditions

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.

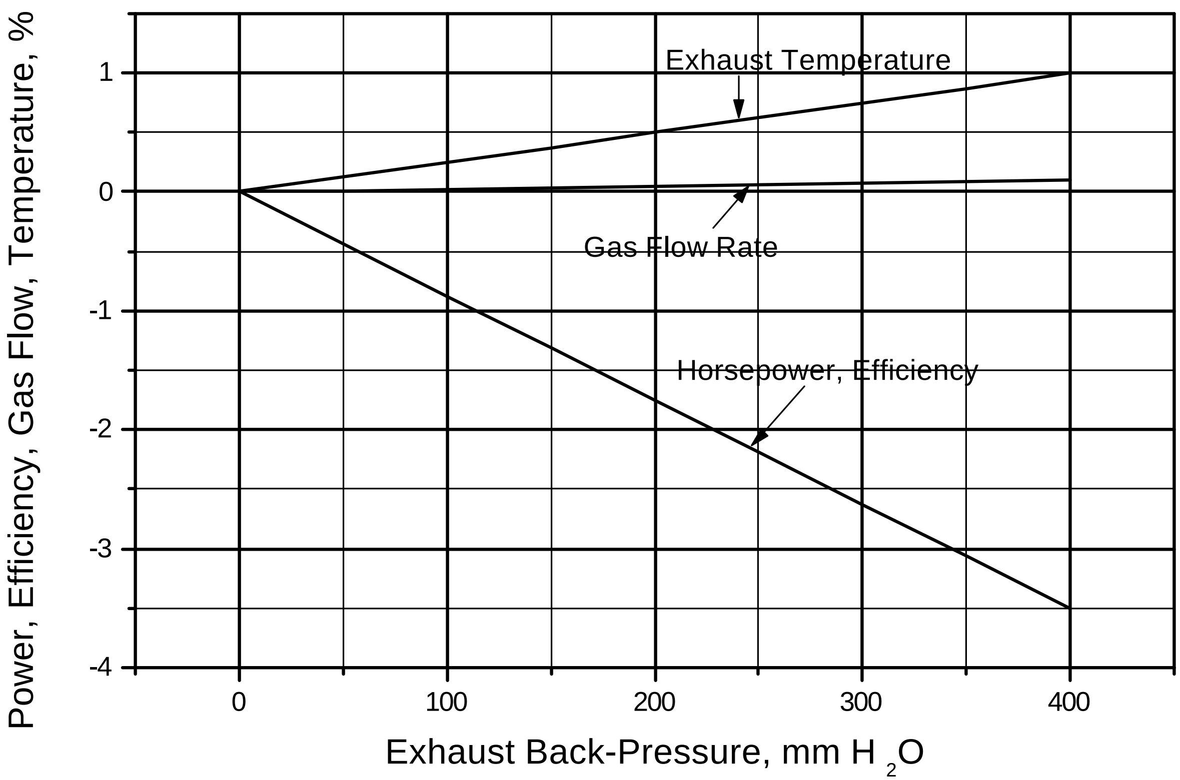


Figure 8. Reducing of GT16000 performances vs exhaust duct losses in ISO 2314 conditions

14. BASIC PARAMETERS AT ISO 2314 CONDITIONS

Table 1

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

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/m^3	830 to 860
15. Acid number, not more than, mg KOH per 100 cm^3 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

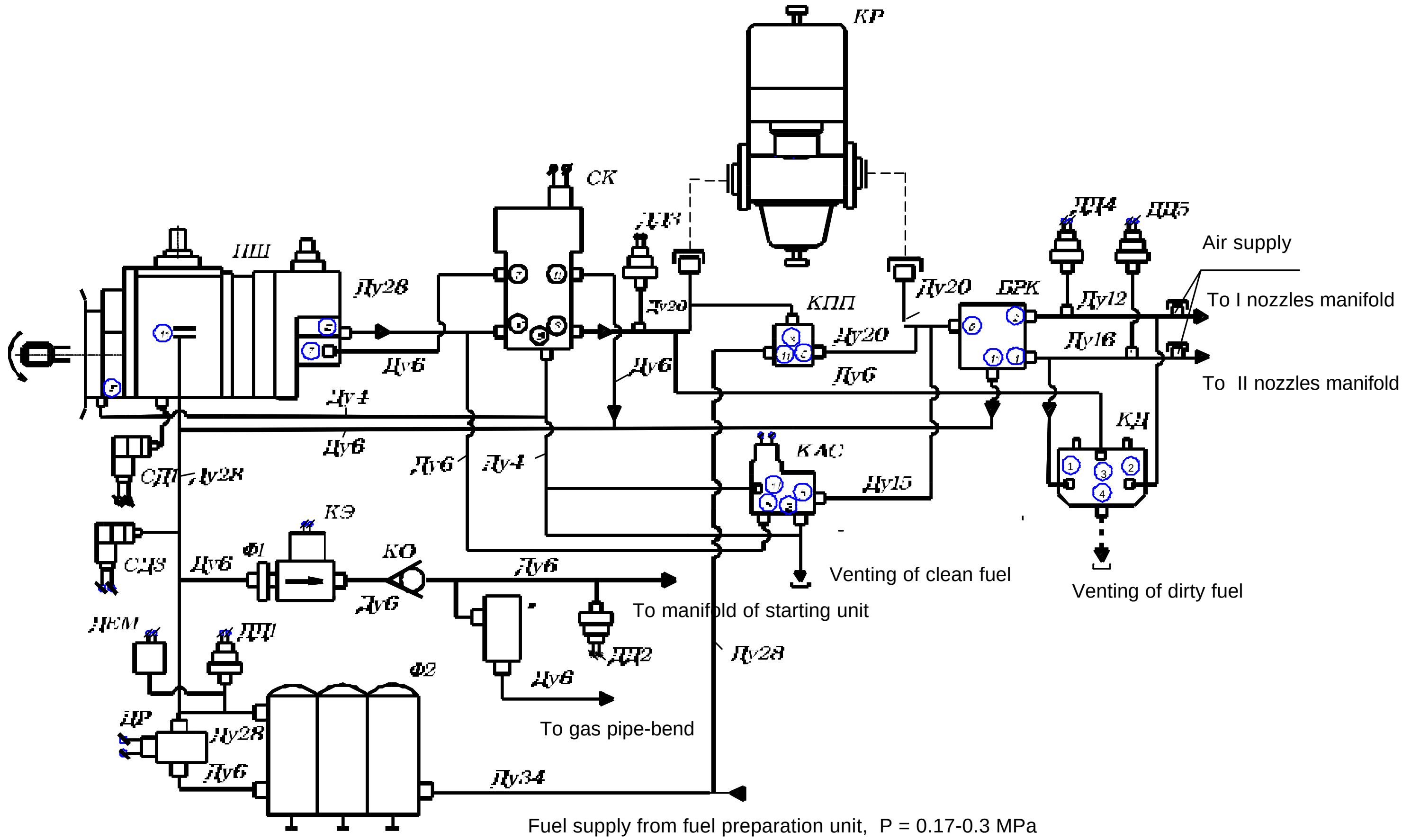


Figure 9. Schematic Diagram of GT16000 Engine fuel system (solid lines — GT16000 pipelines, dash lines — Utility pipelines)

16.1. Fuel system specifications

Table 2

Designation	Name	Number	Notes
ÁÐÊ	Assembly of distribution valves	1	
Ä	Throttle	1	
ÄÄ1-ÄÄ2	"Sapphire" high-precise pressure sensor, output signal 4...20 mA, scale 0..0.6 MPa	2	
ÄÄ3-ÄÄ5	"Sapphire" high-precise pressure sensor, output signal 4...20 mA, scale 0...10 MPa	3	
ÄÅ Ì	Dry contact sensor of pressure, setting P>0.1 MPa	1	
ÄÐ	Dry contact sensor of pressure difference, setting $\Delta P<1.2$ kgf/cm^2	3	
ÊÀÑ	Emergency scavenging valve 074088006		
ÊÄ	Drain valve A90088018	1	
Ê Î	Reverse valve 090518001	1	
Ê Ï Ï	Steady drop valve K49088000	1	
ÊÐ	Governing valve of control system	1	
ÊÝ	Solenoid valve ÌÊÒ-176	1	starting fuel
Ý Í Ø	Gear electric pump Æ59088017-01	1	
ÑÄ1	Pressure indicator, signal at 0.45 MPa	1	
ÑÄ3	Pressure indicator, signal at 0.1 MPa	1	
ÑÊ	Shut-down solenoid valve 075088022	1	
Ô1	Fuel filter 012088010-05	1	
Ô2	Filter P76088040	1	

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

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

* 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

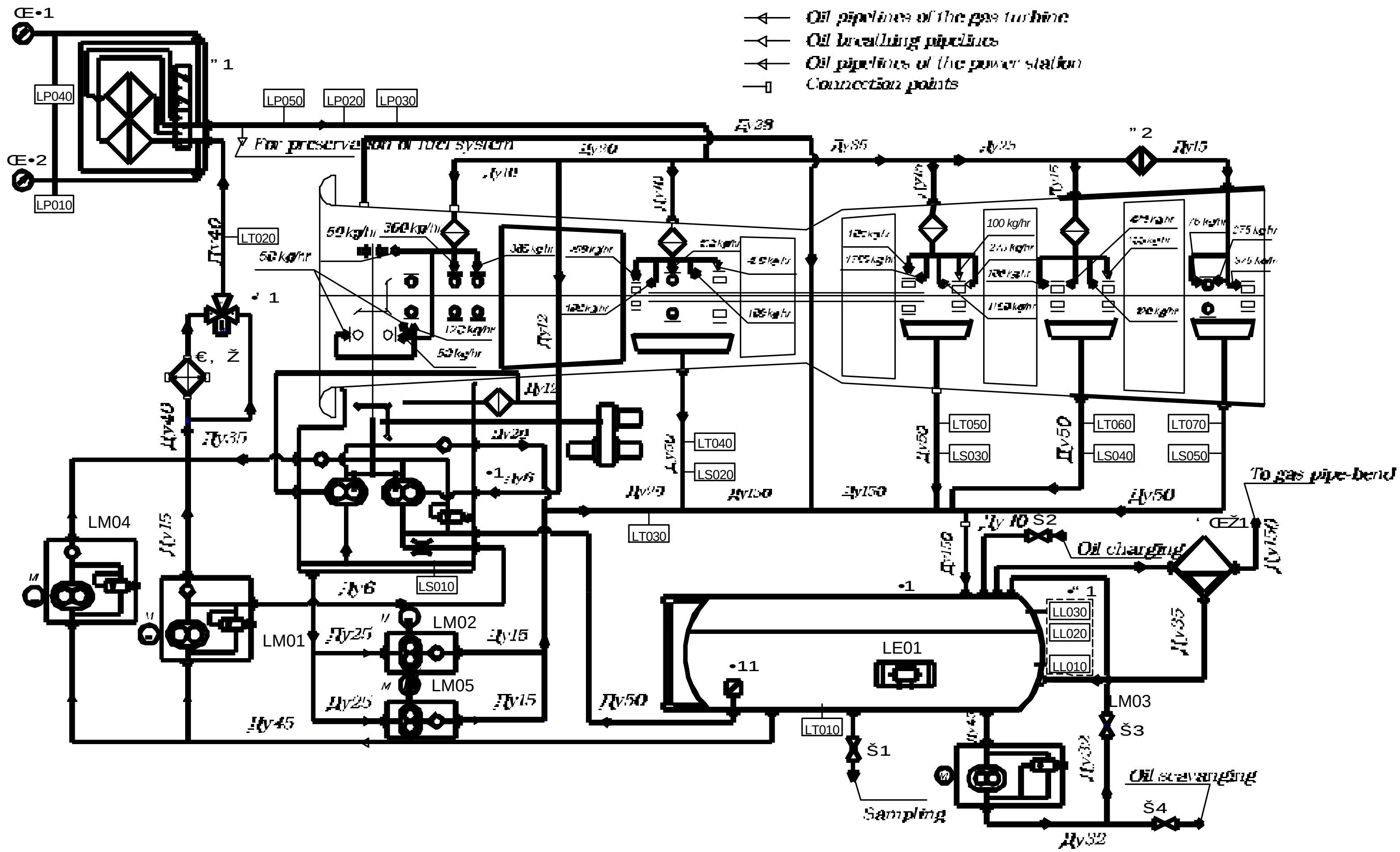


Figure 10. Schematic Diagram of GT16000 Engine lube oil system

18.1. Lubrication system specifications

Table 4

Zone	Designation	Name	Number	Notes
BB	LM04	Boostering oil unit with DC electric drive	1	
5A	LM05	Scavenging oil unit with DC electric drive	1	
5A	LP070	Pressure indicator MCTB-0.2A	1	
6A	LP080	Pressure indicator MCTB-2.5A	1	
7A	LP090	Pressure indicator MCTB-0.4A	1	
		Indicator-Relay of difference in pressure DEM 202-1-01A	1	Adjustment for 8.15 MPa
		Assembly 1 ÇÓ4.075.014	1	
7B	LP100	Pressure drop on Ô1, Ô2 filters		
5A	LP110	Pressure indicator MCTB-0.2A	1	
		Magnetic chip detector Æ59078010:	6	
7A	LS010	at draining out of lower drive box		
6B	LS020	at draining out of the adaptor		
5B	LS030	at draining out of rear casing of high-pressure compressor		
5B	LS040	at draining out of supporting rim of low-pressure turbine		
5B	LS050	at draining out of supporting rim of high-pressure turbine		
7B	LS060	at draining out of main drive support		
		Resistance temperature transducer 5Ö2.821.439-01:	6	
5A	LT010	at the GTE inlet (in the tank)		

Zone	Designation	Name	Number	Notes
6B	LT020	at draining out of the adapter		
5B	LT030	at draining out of rear casing of high-pressure compressor		
5B	LT040	at draining out of supporting rim of low-pressure turbine		
5B	LT050	at draining out of supporting rim of high-pressure turbine		
BB	LT060	at the GTE outlet (in the scavenging line)		in the set
6B	I	Connection M16x1.5 for monitoring oil in ÁÌ1		
6B	II	Connection M24x1.5 for feeding oil for preserving the fuel unit		
7A	ÐÓ1	Level indicator C90078011-02		
7A	LL010	Indicator of minimum level		
7A	LL020	Indicator of maximum level		
7A	LL030	Indicator of emergency level		
BB	AT1	Unit for oil air cooling	1	facility
7A	Á1	Circulated tank	1	
8A	Á11, Á12	Receiving gauze, cell size of 2.5 mm	2	
5B	ÁM1	Tank for oil separation	1	
BB	ÄÐ1	Throttle washer of 1.5 mm diameter		
BA	K1	Shut valve of connection type 521-01.471-02	1	D15
8A	K2	Shut valve D15	1	facility
7B	MH1	Pressure gauge 1MPa, 2.5 accuracy	1	facility
8A	K01	Reverse valve 080078003	1	D70
7B	K02	Reverse valve 080078004	1	D50

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Zone	Designation	Name	Number	Notes
7B	H1	Oil unit 080078020-01	1	
5B	ÐÏÄ	Controller of pressure difference A80088020	1	
BB	CMO1	Static oil separator 080078010	1	
7B	Ô1	Filter 049078003-04	1	filtr. degree 0.01 mm
7B	Ô2	Filter T71078020	1	filtr. degree 0.01 mm
BB	PT1	Temperature controller ÐÒÏ 65-45-1Ì	1	facility
7A	LEO1	Oil heater ÒÝÍ Á-10È220-È1 ÓÕËÇ	1	
8A	LH01... LH03	Automatic valve 005078010	3	
5A	LH04	Shut-down valve 005078005	1	
BB	LM01	Boostering oil unit with electric drive K58078010-01	1	
5A	LM02	Scavenging oil unit with electric drive 080078018	1	
8A	LM03	Oil unit with electric drive 062078001	1	
		Pressure sensor MT100P-11029-02-0.5-1 MPa-42-Ó2-H1	2	
7A	LP010	Pressure measurement point at the engine inlet		
8A	LP020	Pressure measurement point at the scavenging line		
7B	LP050	Pressure monitor MCTB-1A	1	
7B	LP060	Pressure monitor MCTB-2A	1	

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18.2. Requirements to a Utility oil system

1. Applicable oils are listed in Section 17.
2. Maximum operating pressure:
   - 2.1. in boostering 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 ÁÌ1 – 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 Á1 and pipe lines are made of corrosion resistant materials;
   - 5.2. Recommended circulated tank capacity, not less then – 1.5 m^3
   - 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

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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·m^2 650
26. Bearing oil flow rate (per bearing), litre/min 36.7
27. Cooling water flow rate (per machine), litre/sec 25

20. PNEUMATIC SYSTEM

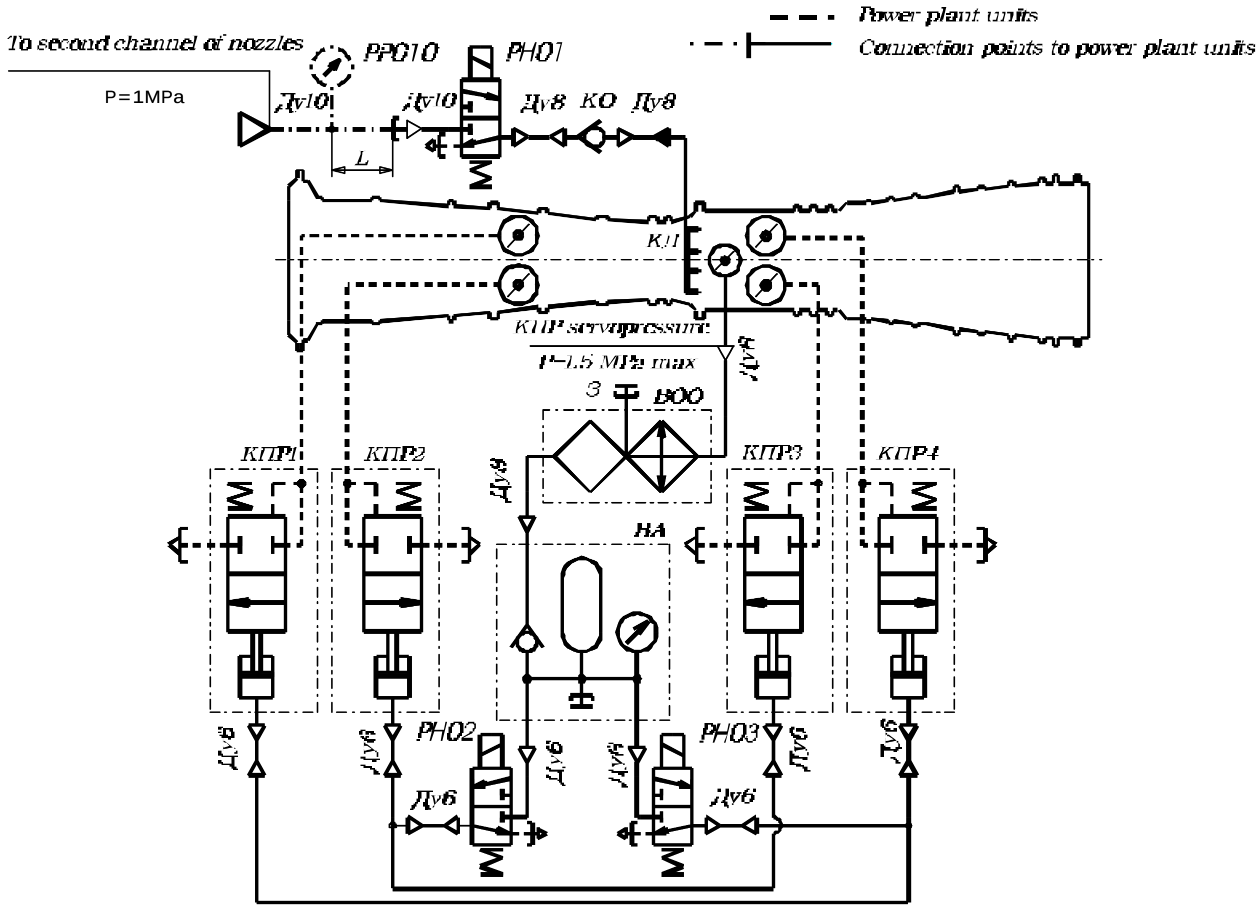


Figure 11. Schematic Diagram of GT16000 Engine pneumatic system

20.1. Pneumatic system diagram specifications

Table 5

Designation	Name	Number	Notes
BA	Air cylinder B71518001	1	
BOO	Refining and cooling unit P76018095	1	
3	Metallic end cup for a drainage connection M16x1.5	1	
ÊË	Fuel manifold	1	
KO	Reverse valve K71518003	1	
Ê Ï Ð1...Ê Ï Ð4	Air bleed valve Ã90038001	4	built in the engine frame
PH01...PH03	Electromagnetic air valve 25MA	3	
PP010	Pressure sensor	1	is not included into the set of delivery

Table 6

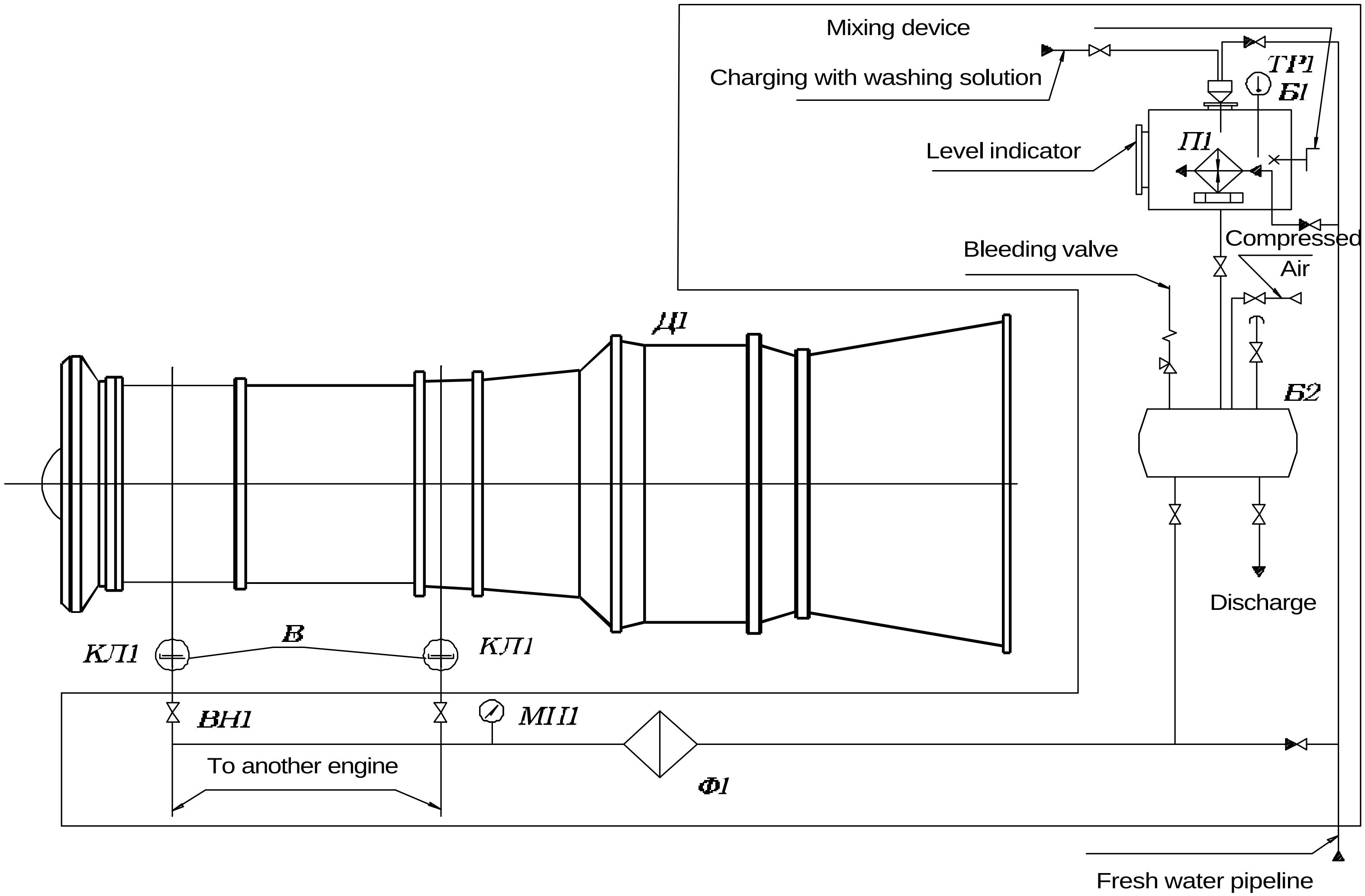
Name of a procedure	Air consumption per a procedure, nm^3	Duration of air supplying, s
Air supplying into a second channel of nozzles at startup	0.9	45

nm^3 is normal cubic metre of free air equalled to m^3 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 ÊÏÐ1...ÊÏÐ4 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



21.1. GTE washing diagram specifications

Table 7

Designation	Name	Number	Notes
Á1	Tank	1	200 litre volume
Á2	Tank	1	20 litre volume
BH1	Shut valve	8	
Ä1	Engine	1	
ÊË1	Washing manifold	2	
MH1	Pressure gauge	2	Local measurement
Ï1	Electric heater	1	
TP1	Thermometer	1	
Ô1	Filter, filtering degree 100 μ, resistance 0.1 MPa	1	
B	Connections for manifolds M27×1.5	2	

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 m^3.
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. ÊË1 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

Unit	3~50 Hz 380 V	1~50 Hz 220 V	–110 V	–27V	Notes
1. Turbine					
1.1. Electric starters	420 kW in peak. 210 kW during 15 s				at startup
1.2. Plasma-jet ignitors	6 kW				at startup
1.3. Temperature Controller				60 W	continuous during operation
1.4. Illumination of turbine container		0.5 kW			optional
1.5. Electric fans for turbine cooling	30kW				continuous during GTE operation and after stop
2. Fuel system units					
2.1. Fuel pump	30 kW				at startup and operation
2.2. Shut-down valve				75 W	at startup and operation
2.3. Starting fuel and air valve				80 W	at startup and stop
2.4. Fuel draining valve				40 W	at operation of thermo-restriction system
3. Lubrication system units					
3.1. Boostering pump	2.2 kW				at startup and up to 20%

Unit	3~50 Hz 380 V	1~50 Hz 220 V	–110 V	–27V	Notes
					MCR
3.2. Boostering pump (reserve)			2 kW		at startup and up to 20% MCR
3.3. Scavenging pump	0.75				at startup and up to 20% MCR
3.4. Scavenging pump (reserve)			2 kW		at startup and up to 20% MCR
3.5. Oil tank cleaning pump	2.2 kW				optional
3.6. Oil heaters	10 kW				optional
4. Automatic control system		1.0 kW	1.0 kW		continuous at operation, reserve power supply –100 V

23. TIME-SPAN OF GTE STARTUP

Table 9

Unit	Time, s	
	ON	OFF
Electric starters	0	155
• first speed	0	65
• second speed	65	155
Ignition unit	85	120
Starting fuel valve	95	120
Starting air valve	100	165
Shut-down valve	100	from the “Stop” button or when protection tripping

24. NOISE LEVEL

24.1. Total noise level, dB

Table 10

At inlet	145
At outlet	142
Without container	135
With container	101

24.2. Octave noise level, dB

Table 11

	Octave Band Centre Frequency, Hz								
	31.5	63	125	250	500	1000	2000	4000	8000
At inlet	125	126	127	125	126	125	141	141	138
At outlet	136	137	140	140	139	136	135	134	129
Without container	112	114	120	124	122	124	127	130	130
With container	112	114	110	104	95	91	89	91	84

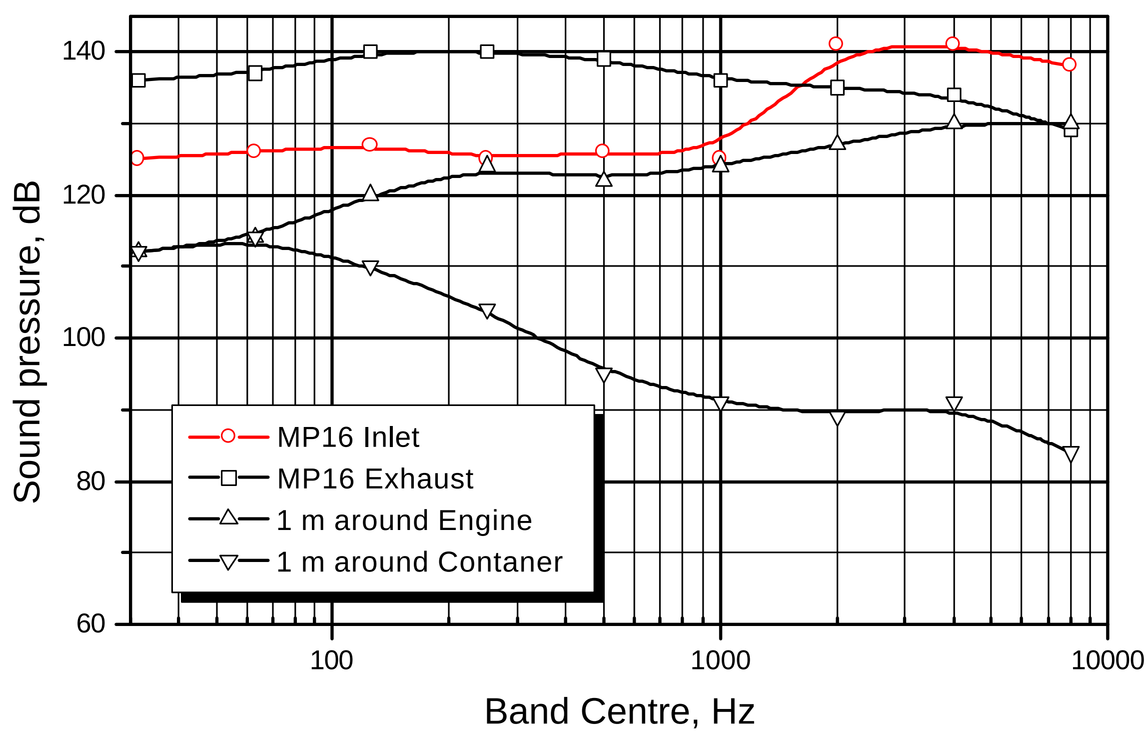


Figure 12. GT16000 Noise Spectrum measured at 1 metre distance

25. GTE INSTALLATION

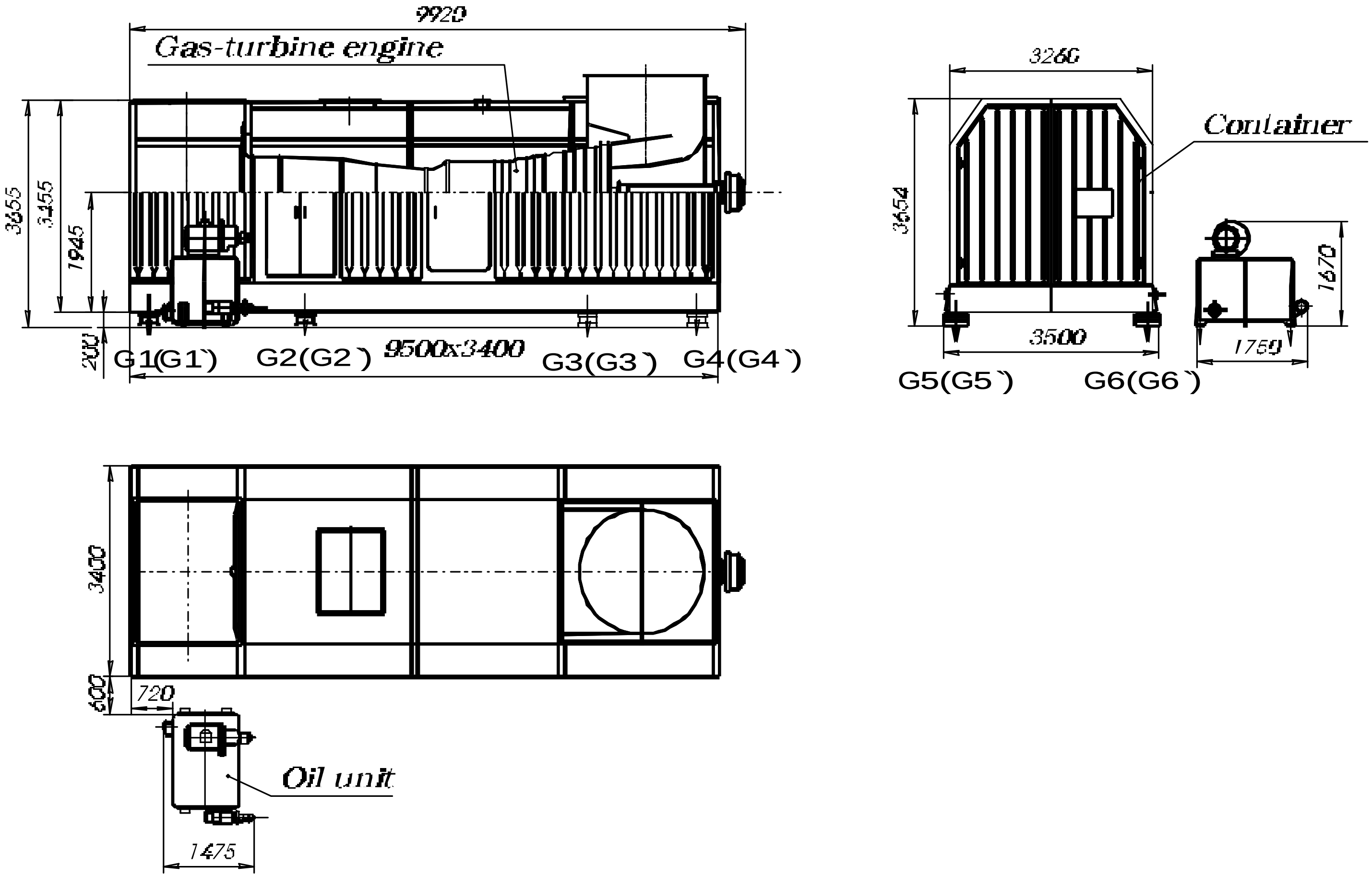


Figure 13. GT16000 container overall dimensions (mm) and foundation anchor points

25.1. Foundation loading

Load	GTE container				Oil unit	
	$G_1(G_1')$	$G_2(G_2')$	$G_3(G_3')$	$G_4(G_4')$	$G_5(G_5')$	$G_6(G_6')$
Static component of weight, kg	1000	6650	3750	1500	600	600
Component of max. torque, kg		±2250	±4500			
Variable component against vibration overloading, max. kg	2000	13300	7500	3000	1200	1200
Maximum value, kg	3000	22200	15750	4500	1800	1800

26. GTE OVERALL DRAWING

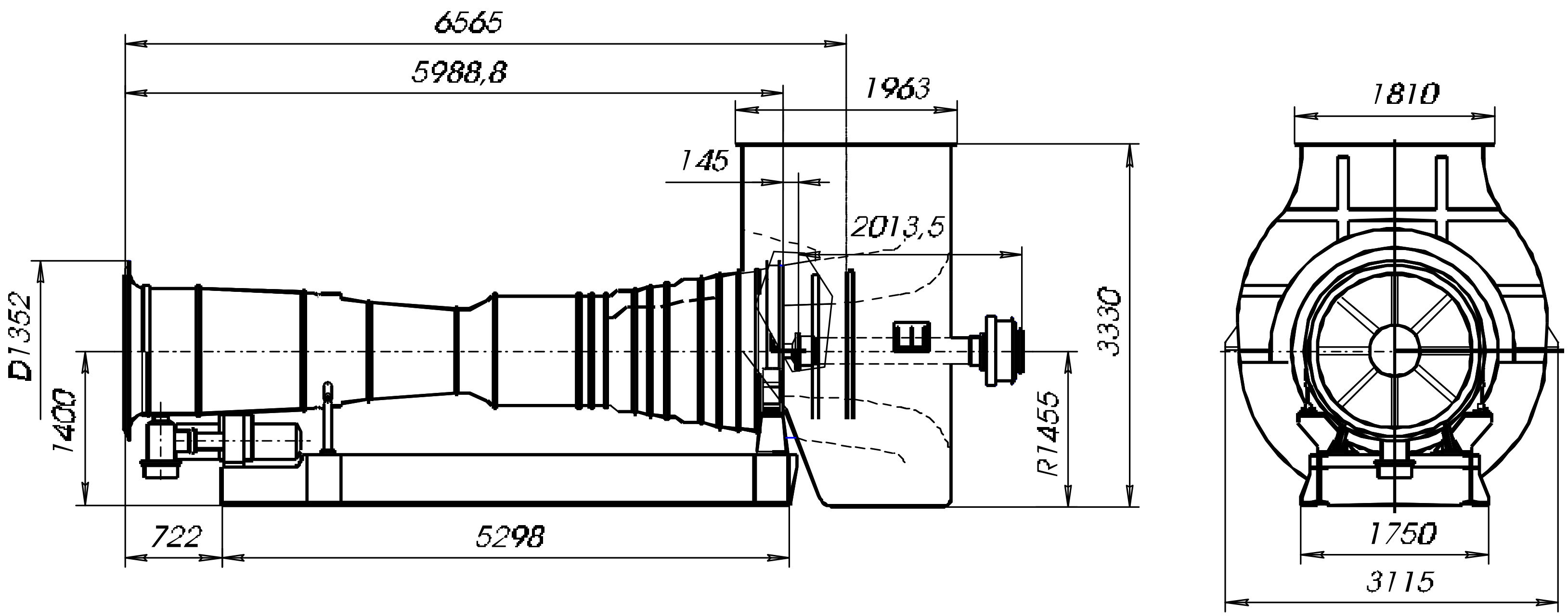


Figure 14. GT16000 overall dimensions, mm

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 hysterisis 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 j = 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. *CO_2 Fire Protection System* for the turbine-accessories-gearbox compartment; the system comprising nozzles, detectors, wiring and interconnection pipes to CO_2 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