Part 6

ADVANCED TECHNOLOGIES AND POWER INSTALLATIONS FOR THERMAL AND ELECTRIC ENERGY GENERATION

6.2. Gas turbine and combined-cycle units

Introduction

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Progress in power engineering is connected today with Gas Turbine Units (GTUs) and Steam and Gas Units (SGUs). Though the first GTU patent was obtained by J. Barber in 1791 in England, i.e. the idea of GTU is known already for more than 200 years, its implementation became possible approximately 50 years ago due to industrial capability. The first gas turbine has been manufactured by the Swiss company BBC (then ABB and nowadays "Alstom").

The simple GTU consists of the compressor, in which the atmospheric air is compressed, the combustion chamber, where fuel and compressed air are fed, and the gas turbine, in which fuel combustion products are expanded. The power, generated by the gas turbine, is much higher, than the power, consumed by the compressor for air compression. A difference between power generation and consumption represents the useful power at the GTU shaft. Simple thermodynamic GTU cycle with fuel burning under constant pressure is shown in Fig. 6.4.

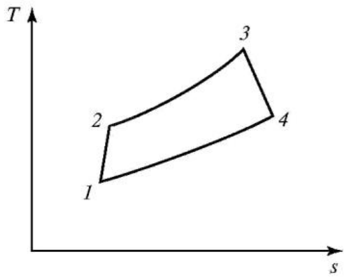

Fig. 6.4. Simple GTU cycle with fuel combustion under constant pressure:
1—2 —air compression in the compressor; *2—3* — heating of fuel combustion products in the combustion chamber; *3—4* — expansion of combustion products in the gas turbine (work); *4—1* — cooling of fuel combustion products (exhaust)

Perfection of GTU as any thermal engine is characterized by efficiency factor — a relation of useful power to heat, supplied to GTU at to fuel combustion.

The efficiency depends on parameters of thermodynamic cycle: relation of an absolute gas temperature at the input to the one at the output, as well as a compression degree — relation of an absolute pressure at the input to the one at the output from the gas turbine, and also on energy losses in the compressor, turbine, in input and output branch pipes, in the combustion chamber, in cooled parts of GTU.

Initial gas temperature at the input to the gas turbine is determined by the progress in materials technology and development of systems of cooling of blades and other parts of the turbine.

Compression degree depends on the compressor design and possibilities of its manufacturing.

Power GTUs, designed for the last years, are based on a simple thermodynamic cycle. Unit capacities of the largest of them make 280 MW, air consumption is more than 600 kg/s.

Gas turbine units, designed on the base of aviation gas turbine engines (GTEs), are constructed with a separated power turbine. Gas for the power turbine is generated in the GTE.

A compressor and a turbine of GTU of the simple cycle are assembled in a general axisymmetric case thus forming a turbine unit. Combustion chambers of large power GTUs are either divided into 10 … 18 flame pipes with a diameter of 350 … 450 mm located around the GTU shaft, or are designed as large-sized, carried out units, vertically installed near or above the GTU.

Small GTU sizes allow its assembly and adjustment at manufactory conditions, and then to transport in the assembled state to the erection place.

Fuel heat, not converted into work in the GTU, can be utilized for central heating, generation of steam for industrial purposes or used in combined (steam and gas) cycles, aimed at obtaining additional work. The thermodynamic cycle of a binary steam and gas unit is shown in Fig. 6.5.

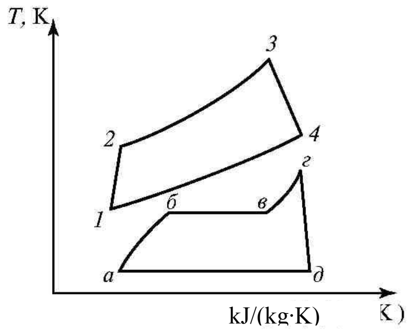

Fig. 6.5. Binary cycle of a steam and gas unit:
1—2—3—4—1 — ref. to Fig. 6.4; *а—б* —condensate heating (feed water) in the heat-recovery boiler; *б—в* — water evaporation in the heat-recovery boiler; *в—г* — steam superheating in the heat-recovery boiler; *г—д* —steam expansion in the steam turbine (work); *д—а* — steam condensation;

Binary SGUs are designed with condensation or heat extraction steam turbines. Electric efficiency of such SGUs in the condensation mode makes 50 … 58 %, in units with heat extraction the fuel heat utilization factor makes 85 … 87 %, and the relation of quantity of the supplied electricity to the supplied heat is more than 1500 kW h/Gcal. For comparison: the maximum relation of the supplied electricity amount to the supplied heat at heat extraction units with steam turbines of T-250/300-240 type makes 750 kW h/Gcal.

SGU characteristics and efficiency of application of gas turbines in combined cycles essentially depend on parameters and characteristics of GTUs. Increase in GTU efficiency raises a share of gas turbine capacity in SGU that improves SGU efficiency and reduces specific costs of the whole SGU.

Since in GTU only pure, almost ash-free fuel is combusted, concentration of ash, carbon monoxide, unburnt hydrocarbon in exhaust gases is considerably lower than the ecological requirements. The most serious environmental issue is generation of nitrogen oxides in GTU combustion chambers. The simplest method of reduction of its concentration in GTU combustion products is injection of water or water steam into a combustion chamber, thus reducing a combustion temperature. Injection of 0,6 … 1,0 kg of water or

0,9 … 1,5 kg of steam for 1 kg of fuel provides NO_x concentration in combustion products below the ecological requirements. GTU capacity thus increases.

The most radical and efficient way to decrease NO_x emissions is creation of “dry” GTU combustion chambers. Depending on GTU load, in order to provide the combustion efficiency and environmental requirements in them, the air distribution between flame pipes is regulated by changing of flow cross-sections of a mixer and bypasses or a number of working burners is changed. Abroad reduction of NO_x emissions in “dry” combustion chambers achieved less than 50 mg/m^3 at 15% of oxygen content in combustion products.

Gas turbine units make significant noise: aerodynamic, magnetic, mechanical. The greatest noise is aroused in an air intake channel of the compressor. Intensity of this noise reaches 155 dB (A), frequency is in the range of 1 … 4 kHz. Its reduction is provided with the silencers, built in the entrance channel and muffling isolation of channel walls. Noise intensity at turbine gas exhaust makes 140 … 145 dB (A). It’s muffling is a more complicated task due to low frequencies (30 … 125 Hz) and high speed of sound under high temperature of gases (450 … 550 °C). The above brings additional difficulties at silencer designing.

Intensity of the noise, coming through GTU case, makes 100 … 110 dB (A) at all octaves. For its reduction the GTU case is closed by a protective casing. As a whole, decrease in GTU noise to sanitary requirements, doesn't cause technical difficulties.

Unlike other thermal engines, applied in power engineering, which have insignificant possibilities of perfection, development of GTU is in progress. This includes an increase in initial gas temperature and turbine efficiency, increase in air consumption and unit capacity.

Improvement of GTU provides an increase in SGU efficiency and its environmental characteristics.

Wide application of SGU at new construction and technical modernization of power plants allows saving to 20 % of fuel in comparison with common steam turbine units with simultaneous reduction of unit capital investments and unit manpower.

Tab. 6.2 presents characteristics of GTU, manufactured in Russia and the Ukraine.

Table 6.2. **Characteristics of gas turbine units, manufactured in Russia and the Ukraine**

Manufacturer	Model	Capacity, MW	Efficiency, %	Compression rate	Initial gas temperature, °C	Exhaust gas temperature, °C	Air consumption, kg/s	Fuel consumption, kg/s
LMZ, St-Petersburg	GTE-160	157	34,4	12,1	1060	537	509	9,26
UTZ, Yekaterinburg	GTE-6	6,12	23,5	6,2	760	415	45	—
	GTE-16	16,46	30,4	11,5	920	420	85	—
	GTE-6U	6,35	31,0	12,0	920	406	33	—
	GTE-25U	32,0	32,5	13,5	1060	466	125	—
NKT “Dvigately NK”,	NK-37	25,0	36,4	23,1	1147	425	—	—
Samara	NK-37-1	30,2	37,3	25,6	1219	455	—	—
OJSC “Saturn”,	AL-31STE	20	36,5	18,1	1252	518	61,7	—
(Moscow — Rybinsk)	GTE-110	110	35,1	14,7	1210	524	360	—
“Aviadvigatel” —	GTU-12PE	12	35	16,9	1049	426	—	51
“Permskie motory”	GTU-16PE	16	37,5	19,6	1143	466	—	57
SPU “Motor”, Ufa	GTE-10/95	10	30,1	8,41	906	478	—	62,4
CIAM — “SOUZ”, Moscow	55ST-20	20	31,7	—	957	457	—	98,0
SPO “Turboatom”, Harkov (Ukrain)	GTE-45-3	54,8	28	7,8	900	475	270	—
SPU “Mashproekt”, Nikolaev (Ukrain)	GTG-6	6	30,5	14,0	1000	410	—	30
	GTG-15 (J-59)	15,8	31,0	12,7	870	360	—	98,5
	GTG-16 (DA-90)	17,0	35,5	19,5	—	427	—	71,0
	GTE-110	110	35,1	14,7	1210	524	360	—