THERMOELECTRIC POWER STATIONS

HEAT CHARACTERISTICS OF V94.2 GAS-TURBINE UNITS OPERATING AT THE PGU-450T COMBINED-CYCLE PLANT OF THE NORTH-WEST COGENERATION PLANT OF ST. PETERSBURG

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Tests of V94.2 gas-turbine units (GTU) of the first PGU-450T plant of the North-West Cogeneration Plant of St. Petersburg are described. The parameters of the GTU and the regular features of their variation are determined in a wide range of operating conditions from idle running to full load. The GTU are characterized by high pressure losses in a cycle, high values of specific power and yield factor, and low concentrations of toxic gases in combustion products at operating modes ranging from 50% load to full load. Quite high efficiencies of the turbomachines are obtained under conditions close to the design ones. The maximum power of 173 MW is attained at a temperature of –10°C and GTU efficiency of 34.5%.

Keywords: gas-turbine unit, combined-cycle plant, binary cycle, tests, thermal characteristics, and variable operating conditions.

The combined-cycle plant PGU-450T operating at the North-West Cogeneration Plant of St. Petersburg is a pioneer binary combined-cycle plant in Russia. The PGU is organized in a 2 + 1 mode, i.e., with two gas-turbine units (GTU), two exhaust-heat boilers, and one stream turbine. The design capacity of the PGU is 450 MW; the efficiency in the condensing mode is about 51% [1 – 4].

PGU-450T employs GTU of type V94.2 of the Siemens Company. This kind of GTU has been produced for a long time during which its parameters were constantly improved.

The GTU has a single-shaft design and has a common two-bearing compressor and turbine rotor (Fig. 1). The turbine group consists of a 16-stage axial-flow compressor and a 4-stage gas turbine.

The exducer of the compressor has a rotary design. It ensures favorable conditions for startup of the GTU and maintains high temperature of exhaust gases after decrease in the load and in ambient air temperature. The extension low-toxicity combustor of the GTU, which can be fired by natural gas and light liquid fuel, consists of two identical vertical bodies located symmetrically with respect to the axis of the turbine group. The walls of its flame pipes are protected on the inside by ceramic tile.

The GTU are equipped with a process control system and the necessary auxiliary systems. They are started by a generator operating in the mode of a synchronous motor with variable frequency provided by a 2.9-MW thyristor starter. The starting time before idle running is 4 min; synchronization and transition to full load require 12 min more (5 min in the case of rapid start). The GTU can operate at any intermediate load (from idle running to rated load) without time constraint.

The GTU was shipped to the power plant in a producer’s assembly 195 tons in mass and mounted under a noise-ab sorbing sheathing forming a container with the necessary life-support systems. At the present time the Leningrad Metal Works (LMZ) produces this type of GTU under license by the Siemens Company under GTÉ-160.

During the commissioning period from the first years of operation the standard measuring equipment of the process control system of the PGU was used to study about 200 operating modes of both GTU. Their analysis provided the characteristics of the GTU on the whole and of their parts (turbomachines and combustors) in the entire load range at ambient temperatures ranging from +28 to –28°C.

During the commissioning period standard measurements were supplemented by recording data of additional

1 All-Russian Thermal Engineering Institute (VTI), Russia, Moscow.
temperature and pressure sensors (designed at VTI) mounted at the outlet from the turbine diffuser.

1. GTU parameters under design conditions. For the conditions of the North-West Cogeneration Plant at 100% electric load the producer guaranteed the following parameters of the GTU:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric power, kW</td>
<td>153,700</td>
</tr>
<tr>
<td>Heat fed to combustor, kW</td>
<td>452,986</td>
</tr>
<tr>
<td>Mean gas temperature at the outlet from turbine, °C</td>
<td>535</td>
</tr>
<tr>
<td>GTU efficiency, %</td>
<td>33.93</td>
</tr>
<tr>
<td>Gas flow rate at the outlet from turbine, kg/sec</td>
<td>514.3</td>
</tr>
<tr>
<td>NOx emissions reduced to standard conditions, mln⁻¹, at most</td>
<td>25</td>
</tr>
<tr>
<td>Sound pressure 1 m away from GTU, dB, at most</td>
<td>80</td>
</tr>
</tbody>
</table>

These guarantees are to be fulfilled under standard ISO conditions, i.e., ambient temperature of 15°C, barometric pressure of 0.1013 MPa, relative moisture content of ambient air of 60%, zero pressure losses at the inlet to the compressor and at the outlet from the turbine, fully opened exducer, and operation on natural gas with low heat value \(Q_i^t = 49.14 \text{ MJ/kg}\) and efficiency of electric generator 98.51%.

The first guarantee test was performed soon after the beginning of operation by specialists of the Siemens Company and VTI.

The tests of GT-11 and GT-12 were performed in turns for one operating unit with the respective exhaust-heat boiler with steam turbine. The second unit was disabled at the period. For any steady mode with loads of 100, 80, and 60% of the rated value the hold time was 1 h. The results of the tests are presented in Table 1.

The values of the air flow rate at the inlet to the compressor and of the gas temperature at the inlet to the turbine were determined according to ISO 23-14.

During the test the GTU was fired by natural gas with a low heat value \(Q_i^t = 47.309 \text{ MJ/kg}\) and efficiency of electric generator 98.51%.

The first guarantee test was performed soon after the beginning of operation by specialists of the Siemens Company and VTI.

The tests of GT-11 and GT-12 were performed in turns for one operating unit with the respective exhaust-heat boiler with steam turbine. The second unit was disabled at the period. For any steady mode with loads of 100, 80, and 60% of the rated value the hold time was 1 h. The results of the tests are presented in Table 1.

The values of the air flow rate at the inlet to the compressor and of the gas temperature at the inlet to the turbine were determined according to ISO 23-14.

At a maximum test load on the GTU \(N_{el} = 156 – 168 \text{ MW}\) the turbines developed a power \(N_{it} = 326 – 342 \text{ MW}\); the compressor consumed \(N_{ic} = 166 – 170 \text{ MW}\). The yield factor \(N_{el}/N_{it} = 0.48 – 0.49\); the specific power of the GTU \(N_{el}/G_{1c} = 305 – 313 \text{ kJ/kg}\).

These values were obtained at the initial gas temperature at the inlet to the turbine \(t_1t = 1055°C\) and total pressure losses in the GTU cycle \((1 – \pi/\pi_c) \approx 0.045 = 4.5\%\). The differences in the parameters obtained for GT-11 and GT-12 are a consequence of different ambient conditions.

At the rated load \(N_{el} = 153 \text{ MW}\) the consumption of heat in the combustor \(\Delta Q_{com} \approx 452 \text{ MW}\), and the efficiency of the GTU is about 34% (Fig. 2).

At full electric load the efficiency of the GT-11 and GT-12 compressors is equal to 88.1 and 87.9%, respectively; \(G_{1c} = 1.032\) and 1.048, respectively. Extrapolation to the design conditions \((\pi_c = 1.0)\) gives the following values.

<table>
<thead>
<tr>
<th></th>
<th>GT-11</th>
<th>GT-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\eta_{ic}), %</td>
<td>88.3</td>
<td>88.6</td>
</tr>
<tr>
<td>(\bar{G}<em>{1c} = (G</em>{ic}\sqrt{T_{1c}/P_{1c}})/(G_{ic}\sqrt{T_{1c}/P_{1c}})_{comp})</td>
<td>1.01</td>
<td>1.01</td>
</tr>
</tbody>
</table>

The efficiency of the compressor is quite high relative to the known variants.

The values of \(\eta_{ic}\) and \(G_{1c}\) for the gas turbine at loads close to the rated value are presented below.

<table>
<thead>
<tr>
<th></th>
<th>GT-11</th>
<th>GT-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\eta_{ic}), %</td>
<td>88.0</td>
<td>88.0</td>
</tr>
<tr>
<td>(\bar{G}<em>{1c} = (G</em>{ic}\sqrt{T_{1c}/P_{1c}})/(G_{ic}\sqrt{T_{1c}/P_{1c}})_{comp})</td>
<td>0.998</td>
<td>0.996</td>
</tr>
</tbody>
</table>

It should be taken onto account that the available power \(N_{el} = G_{1c}\Delta t_{el} = G_{1i}T_{1i}\psi(\pi_c)\) in the computation of the turbine efficiency \(\eta_{ic} = N_{el}/N_{el}\) was determined with the use of \(G_{1i}\) and \(T_{1i}\) values determined according to ISO 23-14, i.e., under the assumption that the air is not spent for cooling. This method underestimates the turbine efficiency by about 0.25% for each percent of the cooling air.