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GAS-TURBUNE SUPERSTRUCTURES AT INDUSTRIAL COMBINED HEAT AND POWER STATIONS WITH BACKPRESSURE STEAM TURBINES

Relationships between the main performance characteristics of the combined plants on the basis of industrial combined tat and power stations with gas-turbine superstructure are determined.

Keywords: *steam turbine, gas turbine, backpressure turbine, thermoelectric stations.*

Introduction

Combined production of thermal and electric energy is an advanced technology that enables more efficient use of organic fuel and reduction of atmosphere pollution. In spite of the considerable progress in the development of combined heat and power stations (CHP) in Ukraine, a centralized heat supply to a large number of consumers is realized from boiler houses rather than from heat stations. Efficient CHP operation depends on the availability of constant thermal loads. But current situation is such that due to the reduction of technological steam consumption at industrial CHP it is impossible to generate the design powers. Besides, it is necessary to take into account the shortage of electric energy after full deactivating of Chernobyl atomic power station.

Industrial CHP equipped with low-power (1, 5 – 6 MW) backpressure steam turbines are included into a large number of processing enterprises. Such steam-turbine plants (STP) have no condensers and are characterized by high power efficiency and heat productivity. In STP of this type a share of energy generated for heat consumption (relation of electric power to heat power from 0,08 to 0,2) is inconsiderable and variable. At present many backpressure SPT at CHP stations are underloaded or deactivated whereas SPT with backpressure turbines can supply steam not only to industrial enterprises but also to individual consumers. As to the increase of electric power generation at CHP, this problem is solved by using gas-turbine plant (GTP) superstructures at the existing steam turbine CHP [1 – 3]. Gas turbine superstructures at the existing CHP enable considerable increase of additional electric energy generation and saving fuel in a power system. Efficiency of GTP application at condensing power stations, i.e. for simpler combined plant circuits, is determined in [4].

Taking the above-mentioned into account, the goal of this work is to determine performance characteristics of the industrial CHP with backpressure turbines superstructures on gas turbine plants.

Main results

Basic thermal circuit of the combined plant on the basis of a backpressure turbine and GTP is shown in fig. 1 with the following designations: steam consumption (D_0), pressure (P), temperatures (t), enthalpy (h).

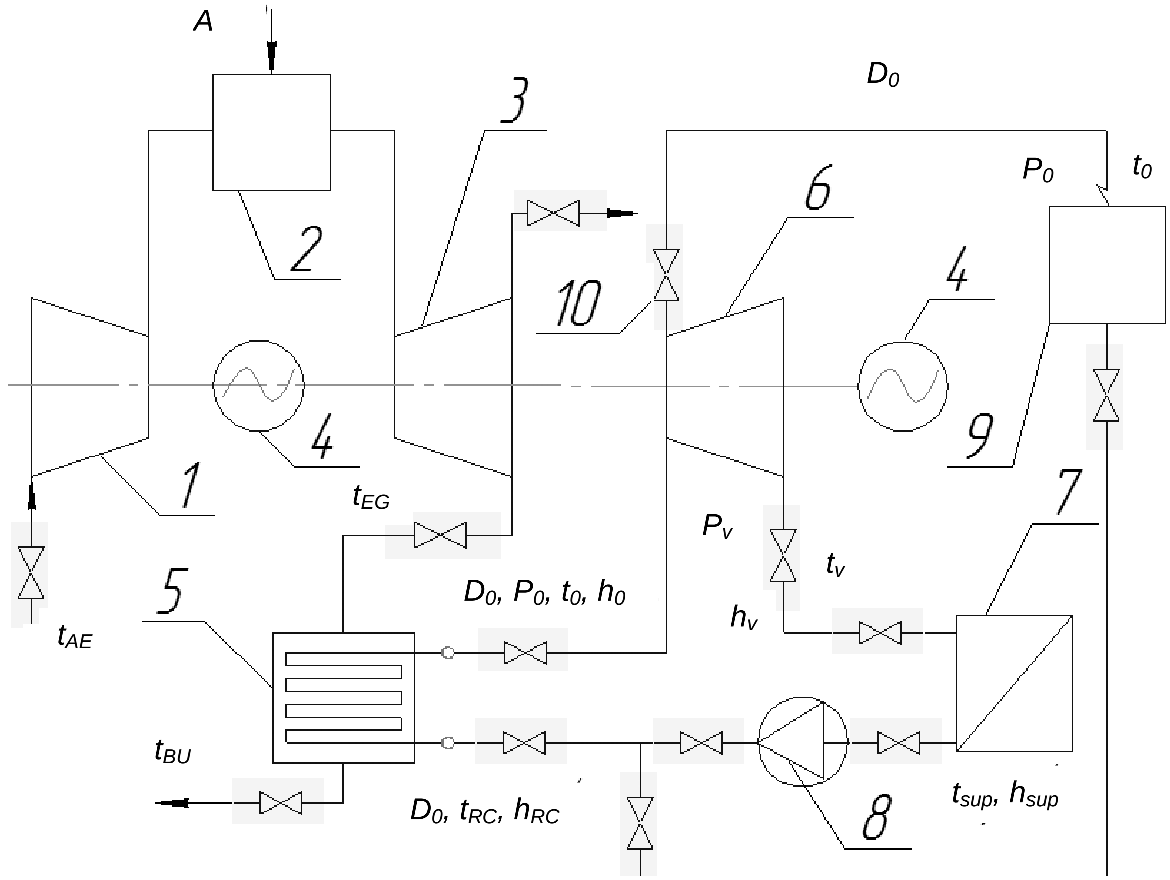

Fig. 1. Basic circuit of a gas-steam CHP: 1 – GTP compressor; 2 – GTP combustion chamber; 3 – gas turbine; 4 – electric generator; 5 – boiler-utilizer; 6 – steam backpressure turbine; 7 – condensate return pump; 9 – steam boiler; 10 – valving

Compressor (1) compresses the air from the environment and pumps it into the combustion chamber (2), where the working fuel (liquid or gaseous) is burnt with flow rate B. Combustion products are supplied to the gas turbine (3) where the shaft rotation work is performed. This work is converted into electric energy in electric generator (4). From gas turbine the exhaust gases with the temperature t_{EG} are directed to the boiler-utilizer (5) where, after cooling to the temperature t_{BU} they generate a superheated steam with parameters P_0, t_0 and flow rate D_0. The steam performs work in turbine (6) and with the parameters P_P , t_P , h_P is supplied to heat consumers (7). The return condensate with parameters t_{RC}, h'_{RC} is returned back to the boiler-utilizer (BU) by the return condensate pump (8). This combined plant is capable of both combined and individual operation. In the case of separate operation the steam boiler (9) operates instead of BU. Let us consider the main performance characteristics of the plant.

The flow rate of the conventional fuel in GTP [4]

$$B_G = N_G / (\eta_G \cdot Q_G), \quad (1)$$

where N_G – GTP electric power; η_G – GTP efficiency; Q_C – heat of the conventional fuel combustion that is equal to 29,3 MJ / kg.

Heat power of the boiler-utilizer [4]

$$Q_{BU} = N_г \cdot \psi\ (1 - \eta_G)/\ \eta_G = N_G \cdot \varphi, \quad (2)$$

where ψ = $(t_{EG} - t_{BU})/(\ t_{BU} - t_{нс})$ – heat utilization coefficient of GTP exhaust gases; t_{EA} – temperature of the environmental air that according to international regulations must be equal to

15°C.

In order to simplify calculations, the values of coefficient φ are given in fig. 2.

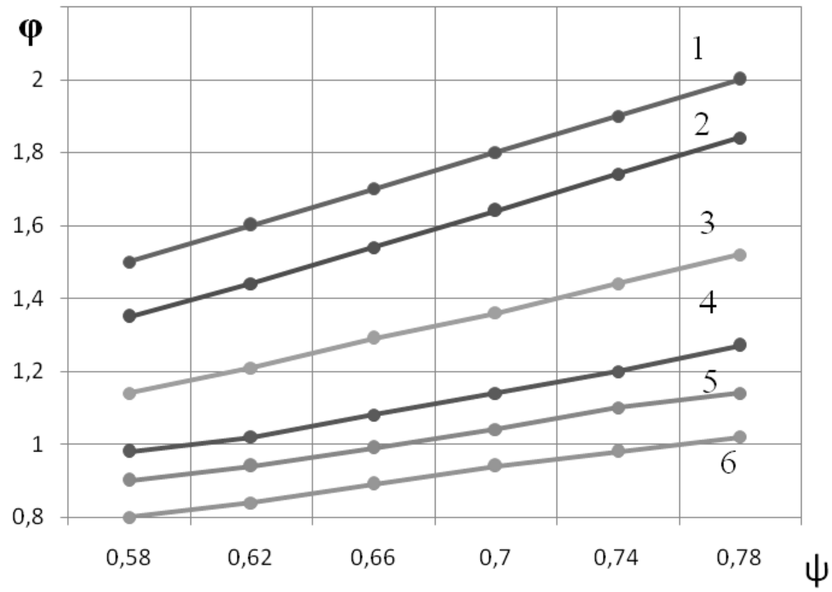

Fig. 2 . Values of φ in formula (2): 1 – η_G = 0,28; 2 – 0,3; 3 – 0,34; 4 – 0,38; 5 – 0,42; 6 – 0,46

It is evident that in the case of combined GTP and STP operation the boiler-utilizer power must be equal to the power of STP, i.e.

$$Q_{BU} = Q_{SC} + N_S = N_S\,(1 + e)/e = N_S\,\varepsilon, \tag{3}$$

where N_S – electric power of STP; Q_{SC} – heat power of the steam consumers;

$e = N_S / Q_{SC}$ – coefficient of the electric energy generation during heat supply process.

Comparing (2) and (3), we obtain

$$N^* = N_G / N_G = \varepsilon / \varphi. \tag{4}$$

The last formula makes it possible to determine electric power of the gas-turbine superstructure of STP with a backpressure turbine. To find rapidly the value of N^* a plot is built (fig. 3).

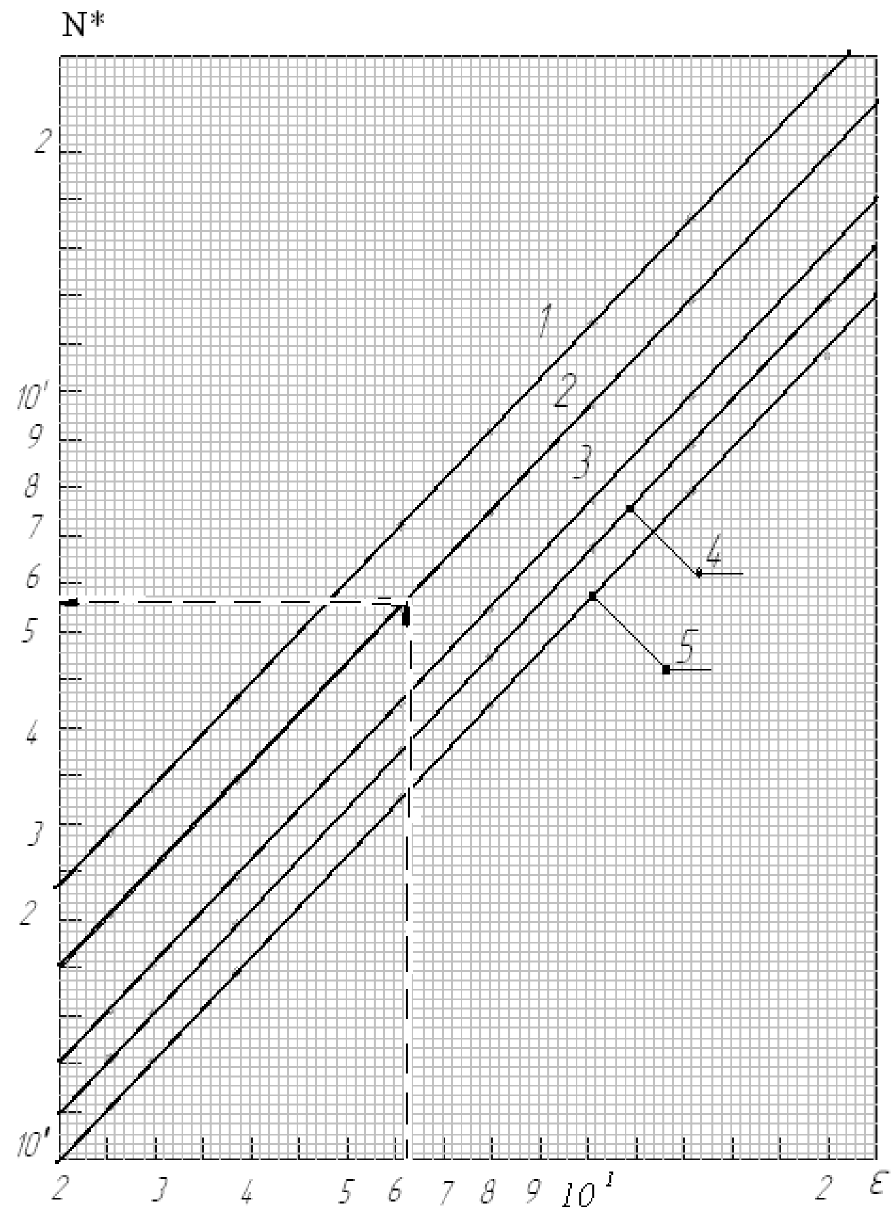

Fig. 3. Values of the relative electric power according to formula (4): 1 – φ = 0,9; 2 – 1,2; 3 – 1,5; 4 – 1,8; 5 – 2,1

In the case of separate STP operation the conventional fuel flow rate in the steam boiler equals

$$B_S = (N_S + Q_{SC})/(Q_C \cdot \eta_B) = N_S \varepsilon /(Q_C \cdot \eta_B)\,, \tag{5}$$

where η_B – the steam boiler efficiency.

Taking into account (1) and (5), we obtain

$$B_G - B_S = N_S / Q_C\,(\varepsilon /\varphi - 1/ \eta_B), \tag{6}$$

$$B^* = B_G / B_S = \eta_B/(\eta_G \cdot \varphi). \tag{7}$$

Formula (7) shows how many times the conventional fuel flow rate in GTP must be greater than the conventional fuel flow rate in STP. For convenience a monogram is built (fig. 4) for finding the relative flow rate B^*.

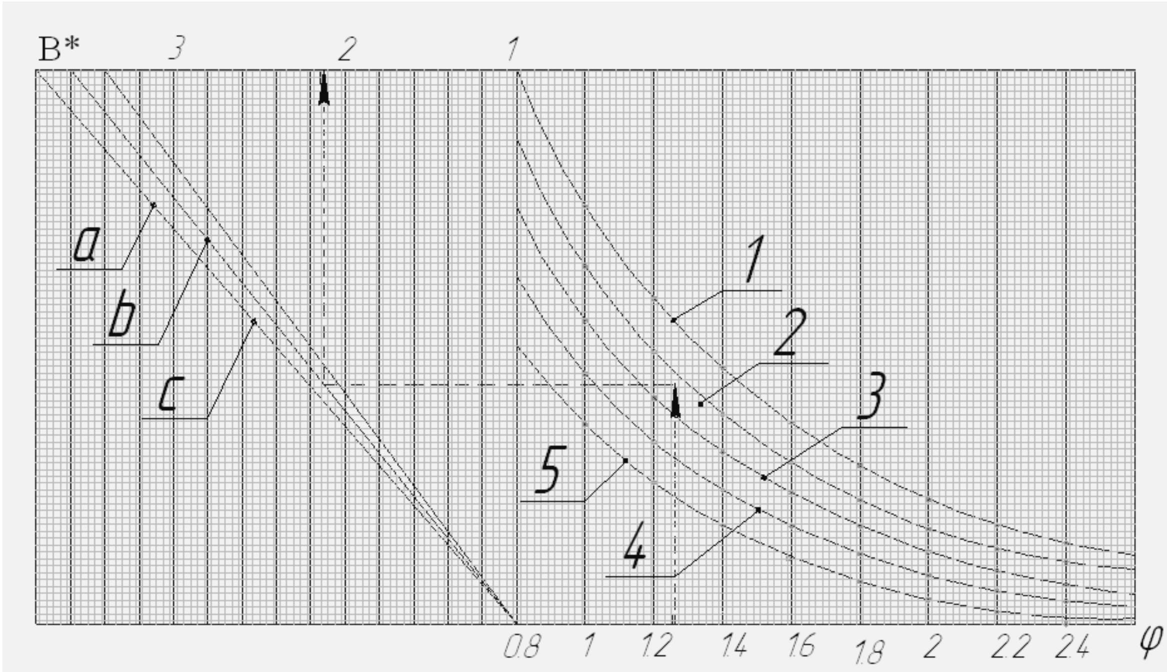

Fig. 4. Nomogram for finding B^* in formula (7): 1 – $\eta_{\text{г}}$ = 0,3; 2 – 0,34; 3 – 0,38; 4 – 0,4; 5 – 0,44; a – $\eta_{\text{к}}$ = 0,94; b – 0,9; c – 0,86

Total power generated at GTP – CHP

$$Q_T = N_G + N_S + Q_{SC} = N_S \varepsilon\ (1 + \varphi)/\varphi = N_S \varepsilon\ \alpha. \tag{8}$$

Power efficiency of GTP – CHP is uniquely estimated by means of the conventional fuel specific flow rate [5], the value of which (kg/GJ) in our case is equal to

$$b = B_G / Q_T = 10^3 / [\eta_G \cdot Q_C\ (1 + \varphi)]. \tag{9}$$

To estimate rapidly the power efficiency of the gas turbine superstructure at industrial CHP with backpressure turbines the relationships presented in fig. 5 could be used.

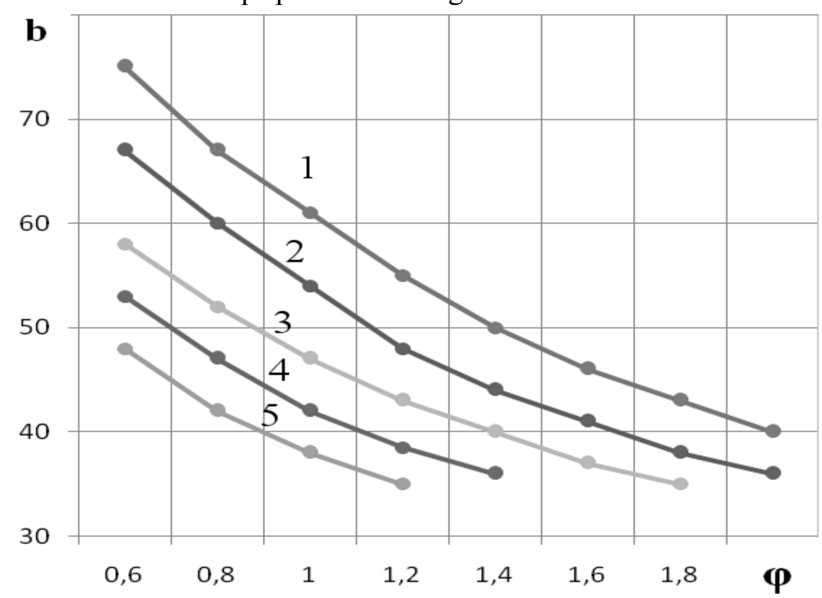

Fig. 5. Values of the conventional fuel specific flow rate for combined heat and electric power generation: 1 – η_G = 0,28; 2 – 0,32; 3- 0,36; 4 – 0,4; 5 – 0,44.

Thus, the formulas are obtained for convenient engineering calculations as well as the plots and the nomogram are built to determine performance characteristics of the combined power plants included into GTP and STP with backpressure turbines. These results are the necessary background for gas turbine superstructure implementation at the industrial CHP. Let us illustrate this by the example. Let it be necessary to choose GTP for STP superstructure with backpressure turbine P-4-35/3 that has the following characteristics [6]: electric power 4 MW; pressure and temperature of the steam in front of the turbine 3,5 MPa and 435°C correspondingly; steam pressure behind the turbine 0,3 MPa; steam flow rate per turbine 35,6 t/h; feedwater temperature 105°C; the power of steam consumers 23,9 MW.

Coefficient of the thermal electricity supply and the value of ε in (3)

$\varepsilon = N_S / Q_{HC}/23{,}9 = 0{,}1673$; $\varepsilon = (1 + 0{,}1673)/0{,}1673 = 6{,}975$.

Let us choose domestically produced GTP from the nomenclature of the scientific-production enterprise (SPE) "Mashproekt", Mykolayiv. We select GPT with the highest efficiency (η_G= 0,36) and the temprature of gases behind the turbine t_{EG} 490°C. To provide the required temperature difference in BU, the temperature behind BU is taken to be 160°C.

BU heat utilizaion coefficient

$\Psi = (t_{EG}\ t_{BU}(\ t_{EG}\ \ t_{EA} = (490 - 160)/(490 - 15) = 0{,}694$.

From fig. 2 we find φ in (2): $\varphi = 1{,}23$.

From fig. 3 we find the value of N^* that is equal to 5,8.

The required GTP power, MW

$N_G = N^* \cdot N_S = 5{,}8 \cdot 4 = 23{,}2$.

Our final choice is the turbine ГТ-25 produced by SPE "Mashproekt", Mykolayiv, with

$H_G = 0{,}36$ i $t_{EG} = 490°C$.

conventional fuel flow rate in GPT according to (5), kg/s

$B_S = (4 + 23{,}9)/(29{,}3 \cdot 0{,}9) = 1{,}05$.

From fig. 4 we determine the value of B^* in formula (7): $B^* = 2{,}15$.

The required conventional flow rate for GTP superstructure, kg/s

$B_G = B^* \cdot B_S = 1{,}05 \cdot 2{,}15 = 2{,}25$.

Let us check GTP conventional fuel flow rate (1), kg/s

$B_G = N_G/(\ \eta_G \cdot Q_C) = 23{,}2/(0{,}36 \cdot 29{,}3) = 2{,}2$.

From fig. 5 we determine the specific flow rate of the conventional fuel at the combined plant:

$b = 42{,}5$ kg/GJ.

Let us check this value by formula (9), kg/GJ

$b = 10^3/[0{,}36 \cdot 29{,}3(1 + 1{,}23)] = 42{,}51$.

Thus, application of the presented graphic material provides the required accuracy of calculations. It should be also mentioned that the value of the conventional fuel specific flow rate in the combined plant is half that of GTP.

Conclusions

1. It is feasible to use gas turbine superstructures at the industrial CHP to increase electric power generation in the region.
2. At the industrial CHP with backpressure turbines the electric power production can be increased by 5 – 6 times by means of gas turbine superstructure application.
3. The efficiency of GTP – CHP with backpressure steam turbines is double that of GTP.
4. The obtained formulas and graphic material make it possible to achieve sufficient accuracy in finding main performance characteristics of CHP with gas turbine superstructures and are the necessary background for GTP selection and for evaluation of the combined plant power efficiency.

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