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ENERGY CHARACTERISTICS OF TURBOGENERATORS AND EFFICIENT MODES OF THEIR LOADING

There had been presented the calculation method and energy characteristics of turbo generators. There had been analysed the efficiency in joint operation of power supply units which have different heat characteristics.

Key words: *Steam turbine, heat characteristic, coal equivalent, specific discharge of coal equivalent, power supply unit.*

Introduction

Thermal electric power stations (TEPS), using the organic fuel, are the base of energy power system. Fuel consumption may be reduced due to the application of the latest technologies [1] (active method of efficiency improvement) as well as due to the rational mode of operating the equipment (specific method). During the operation of some parallel operating turbogenerators there always appears the task of the most efficient distribution of load between them. This task may be solved by energy characteristics. Energy characteristics are called the dependencies of specific discharge of steame, heat, equivalent fuel, efficiency factors on electric loadings of turbogenerator. The real energy characteristics are built upon the results of operational testing. It should be noted that the maneuvering with the load shall be limited by both, minimal and maximal capacity of the equipment. In the process of operation it is necessary to win each smallest part of the percentage of decrease in heat discharge for the production of unit (1 Megawatt hour) of electric energy. The necessary normative material will help the staff execute the efficient operation modes.

Considering the above, there was a task to analyze the joint operation of turbo generators with different energy characteristics and to reveal the most efficient operation modes on specific examples.

Main results

The condensational steam turbine К-100-90 with electric generator and the following steam parameters: the initial pressure 8,8 MPa, initial temperature530 ºC; the final pressure 4 KPa was chosen as an example. The maximum and minimum capacity on the contact terminal of electric generator make up 110 and 30 MW correspondingly. From [2] there had been selected the current values of the steam discharge for the turbine and temperatures of the feeding water depending on the electric load of electric generator N, which are reduced in table 1. These data are the main for the calculation of the energy characteristics.

The specific discharge of steam for the turbine, kg/(KW /h)

$$d = D / N, \tag{1}$$

where N is measured in MW, and discharge of steam D – t/hour.

The specific discharge of the heat, used for the generation of steam in the steam generator for turbine plant without the intermediate steam overheating , kilojoule /kg

$$q_{sg} = \left[\left(h_0 - h_{sw}^{/}\right) + \alpha \cdot \left(h_d^{/} - h_{sw}^{/}\right)\right], \tag{2}$$

where h_0, $h'_{пв}$ *и* $h'_б$ – enthalpy of the overheated steam, feeding and blowoff water from the drum of the steam generator; d – quantity of incessant blow-off, selected in the range of 0,02 – 0,03.

Specific heat, consumed by the turbo generator (power supply unit), MW /(KW /h)

$$q = d \cdot q_{sg} . \tag{3}$$

Total thermal capacity, consumed by the turbo generator (TG), MW

$$Q = D \cdot q_{sg} / 3,6 \cdot 10^{-3} . \tag{4}$$

Efficiency factor of turbo generator (Gross)

$$\eta = N / Q = 3,6 / q . \tag{5}$$

Specific discharge of coal equivalent, kg/(KW /h)

$$b = 0,123 / \eta . \tag{6}$$

Total discharge of coal equivalent for the power supply unit, kg/s

$$B = b_c \cdot 3,6 / N . \tag{7}$$

On the base of the above- mentioned formulas there had been calculated the current values of energy characteristics, reduced in table 1, and the graphic interpretation of the characteristics is presented in fig. 1 and fig. 2.

Table 1

Current values of energy characteristics

Load of electric generator, MW	Factors						
	D_1, t/h	T_{sw}, °C	d_1, kg/(KW /h)	Q_1, MW	η_1	b_1, kg/(KW /h)	B_1, kg/s
110	400	225	3,63	280	0,393	0,313	9,563
100	366	220	3,66	260	0,384	0,320	8,91
80	296	207	3,71	220	0,363	0,338	7,532
60	238	191	3,96	180	0,333	0,369	6,156
40	180	175	4,51	140	0,286	0,430	4,78
30	155	166	5,16	120	0,25	0,492	4,12

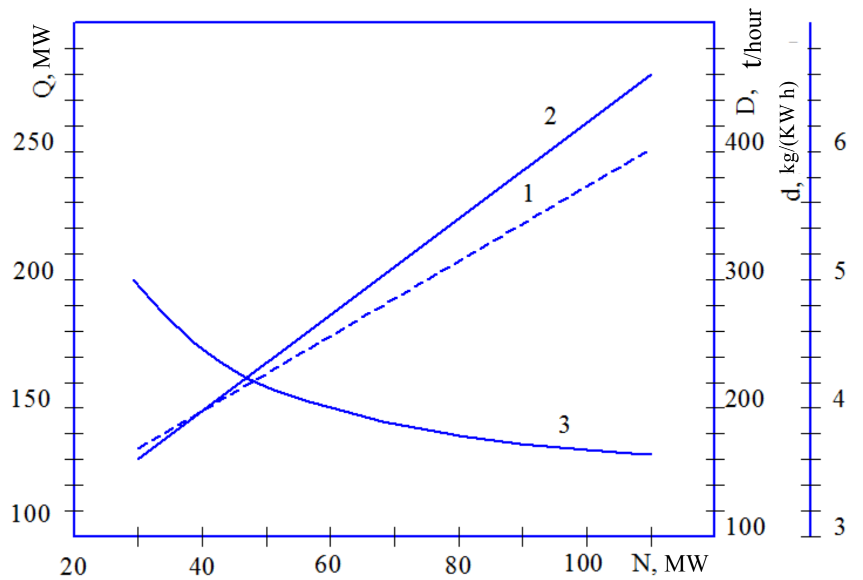

Fig. 1. Characteristics of turbo generator: 1 – discharging characteristics $D = f(N)$;
2 – thermal characteristics $Q_1 = f(N)$; 3 – characteristics of the specific discharge of steam $d_1 = f(N)$

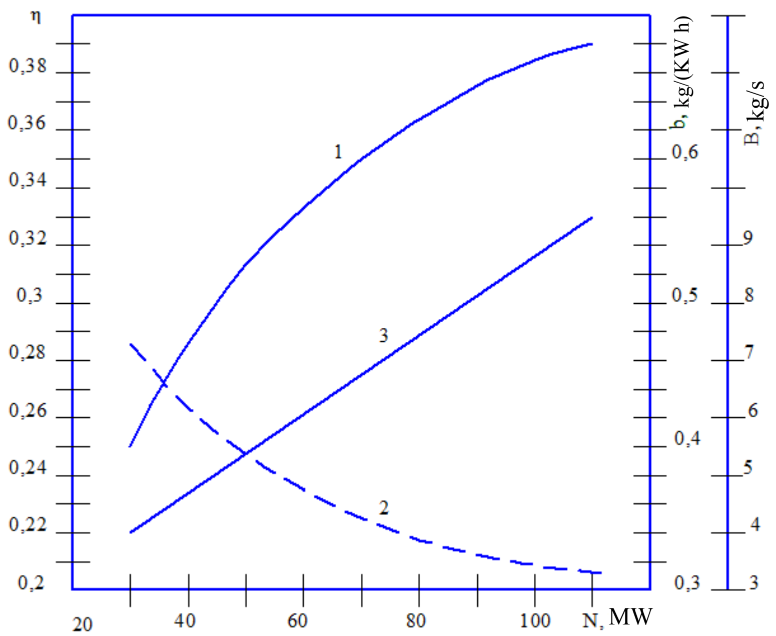

Fig. 2. Characteristics of turbo generator: 1 – $\eta_1 = f(N)$; 2 – $b_1 = f_1(N)$; 3 – $B_1 = f_2(N)$

The above figures show that the thermal $Q_1 = f(N)$ discharge $D = f(N)$, $B = f(D)$ characteristics– linear. For this power supply unit their equations:

$$D_1 = 63{,}125 + 3{,}0625 \cdot N\,;\ \Delta D / \Delta N = 3{,}0625\ t/(MW \cdot hour)\,; \tag{8}$$

$$Q_1 = 60 + 2 \cdot N\,;\ \Delta Q / \Delta N = 2\ MW/MW\,; \tag{9}$$

$$B_1 = 2{,}05 + 0{,}0685 \cdot N\,;\ \Delta B / \Delta N = 0{,}0685\ kg/MW\,. \tag{10}$$

The first summand in the characteristic equation is the value which is consumed for the idle operation of turbo generator, that is, under condition $N = 0$. The second summands in the characteristic equations are the relative gains in values for the unit of electric capacity of turbo generator that is *ΔD/ΔN*, *ΔQ/ΔN*, *ΔB/ΔN*.

The heat characteristic $Q = f(N)$ (see. (4) – (7)) should be considered as the main characteristic (determining) characteristic. It represents the gain in summand thermal losses, since only these losses but not the separate losses determine the efficiency in the turbo generator operation (TG). The relative gain in the summand heat losses, as will be seen further on, may be a reliable criteria of economic load redistribution between separate TG, which operate parallel. This is not difficult to follow the identical character of dependences $d = f(N)$ and $b = f_1(N)$, as well as the reverse character of TG efficiency change.

The operation practice shows that the similar TG have alike but at the same time different characteristics. Let the second TG in TEPS К-100-90 have the heat characteristic, presented in table 2 and in fig. 3.

Table 2

The data of the main characteristics of the second turbo generator

Load of electric generator, MW	Factors						
	D_2, t/h	T_{sw}, °C	d_2, , kg/(KW /h)	Q_2, Mw	η_2	b_2, , kg/(Kw /h)	B_2, kg/s
30	133	0,225	0,546	4,555	30	133	0,225
40	150	0,266	0,462	5,137	40	150	0,266
60	188	0,319	0,385	6,423	60	188	0,319
80	225	0,355	0,346	7,687	80	225	0,355
100	262	0,381	0,322	8,951	100	262	0,381
110	280	0,393	0,313	9,563	110	280	0,393

The comparison of data presented in table 1 and table 2 shows that the second turbo generator К-100-90 operates with lower efficiency then the first one. The equations of linear characteristics are:

$$Q = 78 + 1{,}8375 \cdot N\,;\ \Delta Q / \Delta N = 1{,}8375\ \ MW / MW\,; \tag{11}$$

$$B = 2{,}678 + 0{,}0626 \cdot N\,;\ \Delta B / \Delta N = 0{,}0626\ \ kg / MW\,. \tag{12}$$

Comparing (9) and (10), it is not difficult to see that the second power supply unit has lower relative gain in heat.

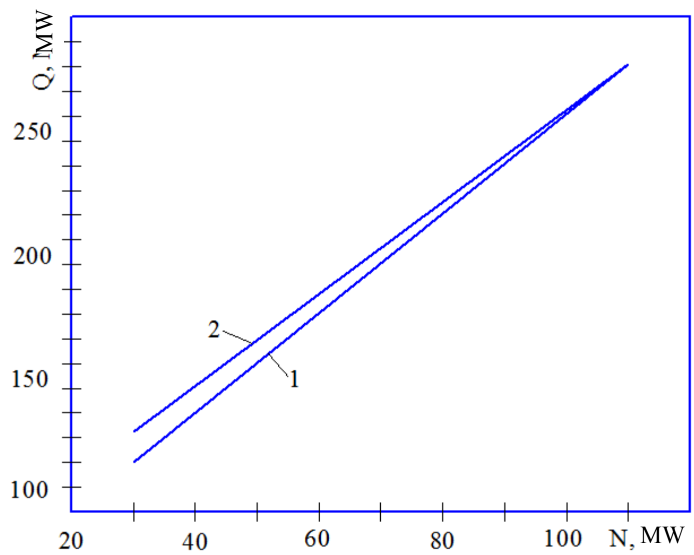

Fig. 3. Thermal characteristics of the first (1) and the second (2) turbo generators

Let the total load of TEPS make up 140 MW. It seems logically to maximum load the turbo generator with high values of efficiency. We try to unload the first TG and load up the second turbo generator. The main factors of some turbo generators and TEPS under this condition are reduced in table 3.

Table 3

Factors of joint operation of turbo generators on TEPS

N_1, MW	Q_1, MW	η	B, kg/s	N_1, MW	Q_2, MW	η_2	B_2, kg/s	N_{TEC}, MW	Q_{TEC}, MW	η_{TEC}	B_{TEC}, kg/s
110	280	0,393	9,563	30	133	0,225	4,555	140	413	0,339	14,118
100	260	0,384	8,9	40	150	0,266	5,137	140	410	0,341	14,037
80	220	0,363	7,53	60	188	0,319	6,423	140	408	0,343	13,95
60	180	0,333	6,156	80	225	0,355	7,687	140	405	0,346	13,84
40	140	0,286	4,78	100	262	0,3816	8,95	140	402	0,348	13,73
30	120	0,25	4,1	110	280	0,393	9,563	140	400	0,35	13,63

The data from table 3 allow to determine the most efficient operation modes of TEPS with any redistribution of load between the power supply units. The above data testify that that the transfer of load from the power supply unit with high efficiency to the power supply unit with low efficiency under certain conditions improves the operating efficiency of TEPS, which is illustrated in fig. 4.

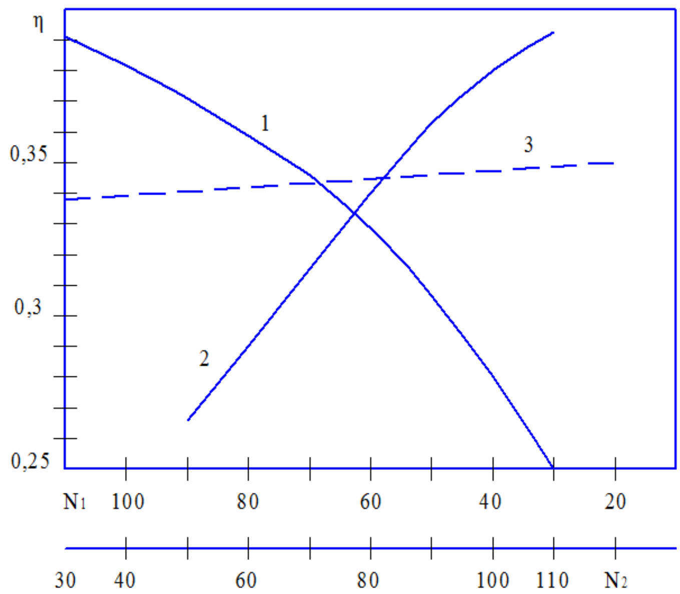

Fig. 4. Values of efficiency factors: 1 – of the first power supply unit; 2 – of the second power supply unit; 3 – TEPS

This is possible only when the thermal characteristics of the turbo generator with smaller values of efficiency has the lower relative gain on heat $\Delta Q/\Delta N$, that is the lower losses of heat during the process of electric energy production. It is not difficult to note that under the operating mode of TEPS with N_1 = 110 MW and N_2 = 30 MW the discharge of coal equivalent makes up 14,118 kg/s, and under the operating mode of TEPS with N_1 = 30 MW and N_2 = 110 MW – 13,63 kg/s. Thus, for TEPS with N = 140 MW there is the economy of coal equivalent which may go up to 1,765 t/h.

Let us now consider the operation of TEPS under condition when the second power supply unit has the thermal characteristic, presented in fig. 5, and the other factors of characteristics are presented in table. 4.

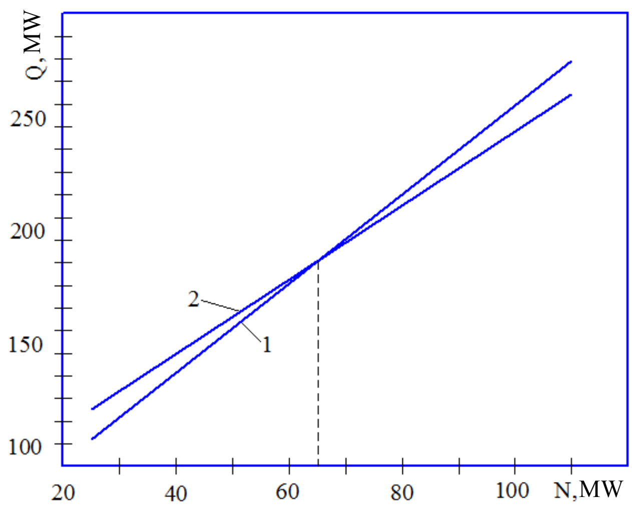

Fig. 5. Thermal characteristics of the first (1) and the second (2) turbo generator

Fig. 5 shows that the equally big efficiency of operation of the first and the second power supply unit is achieved under condition $N_1 = N_2 = 65$ MW. And for$N_2 < 65$ MW the efficiency in operation of the second turbo generator is lower,than that of the first one, and for $N_2 > 65$ MW – vice versa. The equations of thermal and fuel characteristics of the second power supply unit look as:

$$Q_2 = 78{,}57 + 1{,}714 \cdot N\,;\ \Delta Q / \Delta N = 1{,}714\ \ MW / MW\,; \tag{13}$$

$$B = 2{,}708 + 0{,}0583 \cdot N\,;\ \Delta B / \Delta N = 0{,}0583\ \ kg / MW\,. \tag{14}$$

Table 4

Factors of the main characteristics of the second power supply unit

Load of electric generator, MW	Factors						
	D_2, t/h	T_{sw}, °C	d_2, kg/(KW /h)	Q_2, MW	η_2	b_2, kg/(KW /h)	B_2, kg/s
30	130	0,23	0,534	4,456	30	130	0,23
40	150	0,266	0,462	5,137	40	150	0,266
60	180	0,333	0,369	6,156	60	180	0,333
65	190	0,342	0,359	6,493	65	190	0,342
80	215	0,372	0,33	7,347	80	215	0,372
100	250	0,4	0,307	8,542	100	250	0,4
110	267	0,412	0,298	9,122	110	267	0,412

Again it should be noted that in this case the relative gain in heat on the second power supply unit is lower than that on the first. It allows to expect that the transfer of the load to the second turbo generator must exceed the efficiency of TEPS operation. The factors of the joint operation of the power supply units on the TEPS are reduced in the table 5.

Table 5

Factors of joint operation of turbo generators on TEPS

N_1, MW	Q_1, MW	η	B, kg/s	N_1, MW	Q_2, MW	η_2	B_2, kg/s	N_{TEC}, MW	Q_{TEC}, M MW	η_{TEC}	B_{TEC}, kg/s
110	280	0,393	9,563	30	130	0,23	4,456	140	410	0,341	14,02
100	260	0,384	8,9	40	150	0,266	5,137	140	410	0,341	14,02
80	220	0,363	7,53	60	180	0,333	6,156	140	400	0,35	13,685
60	180	0,333	6,156	80	215	0,372	7,347	140	395	0,354	13,528
40	140	0,286	4,78	100	250	0,4	8,541	140	390	0,356	13,32
30	120	0,25	4,1	110	267	0,412	9,122	140	387	0,362	13,21

Data from table. 5 testify that up to the load of 65 MW the first power supply unit operates efficiently. This is explained by the fact that it has the discharge of heat for idle operation lower than the first one. After the load of 65 MW the second power supply unit operates efficiently, since it has lower relative gain in heat, than the first one. So, with the load of up to 65 MW it is expedient to load the first power supply unit, and with loads of over 60 MW – the second. Consequently, the load of the second power supply unit up to the maximum capacity stipulates for the economy of the coal equivalent - ΔB = 2,916 t/h.

Conclusion

1. The efficiency factors and relative to them specific heat discharges may not be the criteria of economic redistribution of load between the power supply units.
2. Heat characteristic is the main characteristic, which helps determine the operation efficiency of heat and power plants.
3. The criterion of economic redistribution of load between the power supply units is the relative gain in heat for electric energy production.
4. To ensure the fuel efficiency it is expedient to load the power supply units with lower relative gain in heat.

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