AD-A190 620 OPTIMIZATION OF SOME PARAMETERS OF ATOMIC STEAM-GAS POWERPLANT(U) FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH Y F RATNIKOV 21 OCT 85 FTD-ID(RS)T-1502-84 1/1

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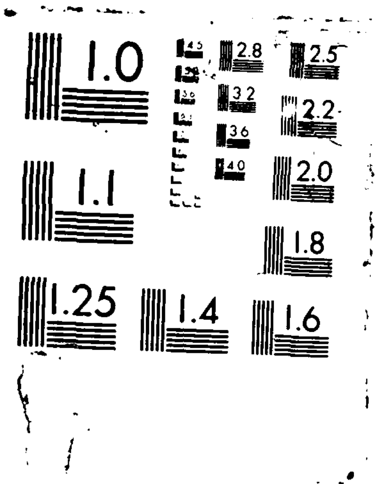
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FOREIGN TECHNOLOGY DIVISION

OPTIMIZATION OF SOME PARAMETERS OF ATOMIC STEAM-GAS POWERPLANT

by

Ye. F. Ratnikov

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

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OPTIMIZATION OF SOME PARAMETERS OF ATOMIC STEAM-GAS POWERPLANT.

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Ural Order of the Red Banner of Labor Polytechnic Institute im. S. M. Kirov.

Determination of optimum parameters of binary type atomic steam-gas powerplant/installation (Fig. 1) is difficult analytical problem in view of complicated interdependence of parameters, which characterize reactor, gas-turbine and steam-turbine parts of the installation. As shown in [1], in the assigned initial parameters of gas and vapor the indices of the thermal efficiency/cost-effectiveness of steam-gas installation depend mainly on three interdependent/interconnected between themselves parameters: pressure ratio in gas cycle (σ), efficiency of steam regenerative cycle (η_t^p) [1] and relation of absolute maximum temperatures of gas cycle (τ).

FOOTNOTE [1]. In this case - temperature of feed water (t_{na}) ENDFOOTNOTE.

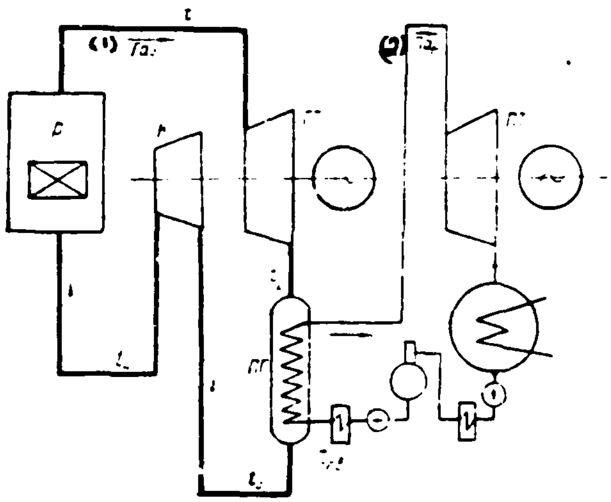

Fig. 1. Schematic diagram of atomic steam-gas installation: R - reactor; K - compressor; GT - gas turbine; PG - steam generator; PT - steam turbine.

Key: (1). Gas. (2). Steam.

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The measures of the economic effectiveness of atomic steam-gas installation (i.e. the cost/value of 1 kW·h), furthermore, they will depend on the size/dimension of capital investments to the installation, and with a change in its parameters - on the variable/alternating capital investments (ΣK). This additionally complicates the problem of calculating the optimum parameters of steam-gas installation. Employing the conventional procedure for the power plants the optimum parameters are found from the conditions of the minimum of expenditures for manufacture by the installation 1 kW·h of electric power, i.e., from the conditions of the minimum of magnitude $З_э$.

In this case, according to [2],

$$З_э = \frac{\left[\delta - \tau - \frac{\tau}{\eta_к}(\sigma^m - 1)\right](\Sigma K_{эксп} - \Sigma K_{вер})}{(1 - \Delta p^m \sigma^{-m})\eta_{гт} - \frac{\tau}{\eta_к}(\sigma^m - 1) - [1 - \tau - (1 - \Delta p^m \sigma^{-m})\eta_{гт}]\eta_t^p \eta_{пт}} \cdot \frac{10^2(p_н + p_а)}{n k_т N_р \eta_м \eta_г \eta_{кв}(1 - \bar{C}_т - \bar{C}_{эк})}. \quad (1)$$

where $p_н$ - reduction coefficient;

$p_а$ - coefficient of damping;

n - number of hours of work of installation per annum;

$N_р$ - heat output of reactor;

$k_т$ - temperature coefficient;

$\eta_м$ - mechanical efficiency;

$\eta_{г}$ - efficiency of generator;

$\Sigma K_{пос1}$ - constant capital investments, which do not depend on change in parameters of installation;

$\Delta p_{вхр}$ - magnitude, which characterizes effect of initial pressure and hydraulic resistor/resistance of gas duct/contour;

δ - ratio of absolute temperatures of coating fuel element to initial temperature;

$\eta_{гт}$ - efficiency of gas turbine;

$\eta_{к}$ - efficiency of compressor;

$\eta_{пт}$ - efficiency of steam turbine;

$\eta_{кп}$ - efficiency considering energy consumption per its own needs;

$\bar{C}_{т}$ - relative propellant/fuel component;

$\bar{C}_{\cdot c}$ - relative operating component.

From (1) it is evident that $З_{э}$ is function of many dependent and independent variable parameters and magnitudes both technical ones and cost ones.

Attempt at definition of optimum parameters ($\sigma_{опт}$, $t_{пв}^{опт}$, $\eta_{i}^{макс}$) analytically does not give necessary results in view of extremely complicated dependences of these parameters both between themselves and with cost indices. Therefore in this work the step by step method of optimization (from the "determining parameter") is accepted. It consists of the following. By thermodynamic calculations for the accepted initial conditions are located the outer limits of the parameters of the steam-gas installation (thermodynamically most advantageous), which correspond to maximum the internal efficiency of cycle (η_{i}). In this case for the determining parameter is accepted pressure ratio in gas cycle (σ), for each variant value of which are located $t_{пв}^{мс}$ and $\eta_{i}^{макс}$. Then within the limits of variant values σ are located absolute outer limits σ, τ, $t_{пв}$, and also $\eta_{i}^{макс}$ (extremum from the extrema). After accepting these parameters for the base ones, we find relative changes in the characteristics of the equipment for steam-gas installation for each value σ.

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Further for the base parameters cost data on the equipment are accepted and general/common/total variable/alternating capital investments for each value of the determining parameter are determined. By calculations on (1) when $З_т^{min}$ are located optimum parameters ($\sigma_{опт}$, $t_{вх}^{опт}$), on which are designed all remaining parameters interesting.

With accepted method defined group of parameters (σ, $t_{вх}$, τ, η_i, t_2, t_3, t_4, Δt_p, $\Delta t_{н}$), which have decisive effect both on characteristics of equipment for steam-gas installation and on cost indices, simultaneously is optimized.

Are given below results of optimization of parameters of atomic steam-gas installation (Fig. 1) indicated at following initial conditions: gas - helium, initial temperature of gas t_1 = 800°C, pressure P_1 = 60 bars, steam parameters 88 bars, 535°C, hydraulic resistor/resistance of gas duct/contour 5%, efficiency: $\eta_{гт}=0.88$, $\eta_к=0.86$, $\eta_м=0.995$, $\eta_г=0.99$, $\eta_{ку}=0.95$.

Calculations were performed on computer(s) "Minsk". Space was taken for σ as the equal to 0.01, and within the limits of the absolute extremes - 0.005.

Results of calculations are given in Table 1. Determining parameter (σ) is varied in limits of 1.6-2.10. The numerical values of the absolute extremes proved to be following: $\sigma_{опт} = 1.75$, $t_{пв}^{опт} = 182^{\circ}C$, $\eta_{t}^{макс} = 0.427$. Table 1 shows a relative change in the parameters and magnitudes with respect to the absolute extreme parameters at the change σ.

For example, it is evident that with the increase σ (more than 1.75) the power of gas turbine ($N_{гт}$) and compressor ($N_{к}$) grow/rise, and steam turbine ($N_{пт}$) - decrease. The expenditure of water for the technical water supply of installation ($W_{тв}$) respectively is reduced.

Table 1 shows also change in other indices, which are changed with change σ, $t_{пв}$ such, as heat output of reactor ($N_{р}$), flow of gas (G), surface of heating steam generator ($F_{пг}$) and regenerative installation of steam turbine ($F_{рег}$).

For defining/determining magnitude of variable/alternating capital investments to specified equipment are accepted following specific cost indices for base value σ: reactor plant - 40, steam turbine (with capacitor and generator) 7, gas turbine (with generator) 5.0, compressor of 2.5 rub/kW, steam generator 100 rubles/m², technical water supply 9 rub/kW (steam power), regenerative heaters of high pressure 30, low pressure 15 rubles/m².

Table 1.

σ	$t_{пв}^{экс}$, °C	τ	η_i	$\frac{\Lambda_г^э}{\Lambda_г^{экс}}$ (1) при $G=const$	$\frac{G^э}{G^{экс}}$ (1) при $Q_р=const$	$\frac{F_{пг}^э}{F_{пг}^{экс}}$	$\frac{\Lambda_{гт}^э}{\Lambda_{гт}^{экс}}$	$\frac{\Lambda_к^э}{\Lambda_к^{экс}}$	$\frac{\Lambda_{пт}^э}{\Lambda_{пт}^{экс}}$	$\frac{W_{тв}^э}{W_{тв}^{экс}}$	$\frac{F_{рег}^э}{F_р^{экс}}$
1,60	280	0,533	0,421	0,855	1,117	1,055	0,830	0,964	0,918	1,049	1,485
1,70	215	0,485	0,425	0,958	1,044	1,045	0,942	0,980	0,988	1,020	1,180
1,75	182	0,454	0,427	1	1	1	1	1	1	1	1
1,80	158	0,455	0,426	1,015	0,985	0,982	1,040	1,050	0,997	0,985	0,641
1,90	104	0,431	0,422	1,056	0,948	0,918	1,128	1,070	0,982	0,923	0,513
2,00	60	0,420	0,419	1,062	0,945	0,900	1,184	1,145	0,945	0,858	0,342
2,10	30	0,408	0,415	1,066	0,937	0,859	1,306	1,222	0,913	0,805	0,000

Key: (1). with.

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Change in capital investments in dependence on power of aggregate/unit was approximated by following equation:

$$K'' = \left[1 + \beta\left(\frac{N''}{N'} - 1\right)\right]K'. \quad (2)$$

where β - coefficient, which considers change in specific capital investments with power change and taken in dependence on type of equipment by equal to 0.06-0.75.

Results of calculations according to expression (1) are represented graphically in Fig. 2-4.

Fig. 2 shows change $\text{З}_э$, $N^{бг}$, q and $t_{пв}^{опт}$ in dependence on σ with constant flow rate/consumption of gas (G = const), at heat output of reactor at point of absolute extremes $N_p = 500$ MW and with propellant/fuel component $\overline{C}_т = 0{,}0,\ 0{,}20$ and $0{,}40$. From Fig. 2 it is evident that optimum pressure ratio lies/rests within limits $\sigma_{опт} = 1{,}67 - 1{,}90$, and the temperature of feed water $t_{пв}^{опт} = 104 - 120$ C. The maximum of electrical power is $N^{бо}_{макс} = 213$ MW (with σ = 1.90), and the minimum of the specific capital investments q = 1[illegible]5 rub/kW (with σ = 1.885). Cost/value 1 kW·h of electric power vary within the range of 0.423 (when $\overline{C}_т = 0{,}00$) to 0.759 kopecks (when $\overline{C}_т = 0{,}40$).

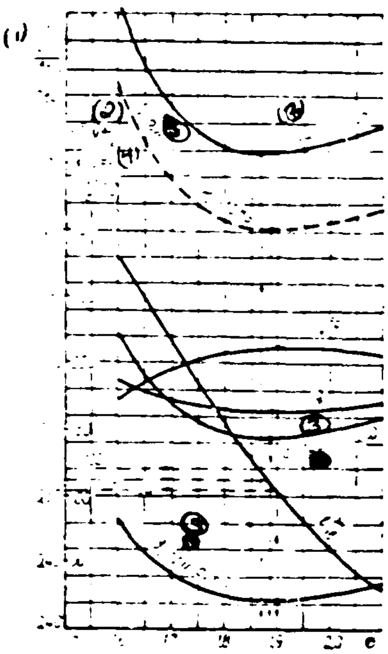

Fig. 2.

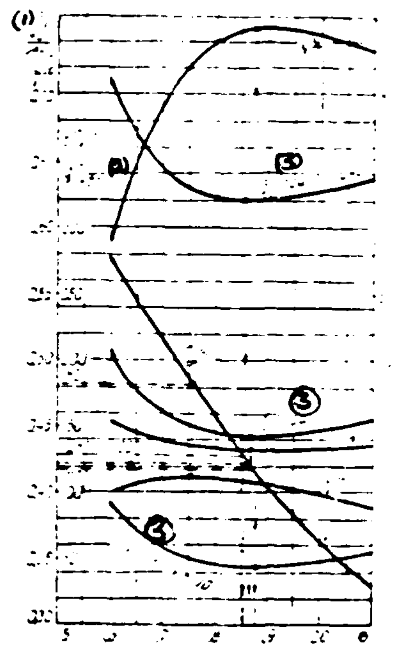

Fig. 3.

Fig. 2. Definition/determination of optimum parameters $(\sigma_{opt}, \eta_{ns}^{opt})$ at G = const (N_p = 500 MW when σ_{sac} = 1.75)

Key: (1). (kop/kW·h). (2) MW. (3). with. (4). (rubles/kW).

Fig. 3. Definition/determination of optimum parameters $(\sigma_{opt}, \eta_{ns}^{opt})$ at G = const (N_p = 2000 MW when σ_{sac} = 1.75)

Key: (1). (kop/kW·h). (2). (rubles/kW). (3). with.

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Comparison of obtained results with data of thermodynamic calculations shows that account of capital investments to installation substantially changes numerical values of parameters. Pressure ratio grows/rises (from 1.75 to 1.90), and the temperature of feed water descends on 60-70°C. This is explained by the fact that with an increase σ (to the definite/determined value) the expenditures for the steam part of the steam-gas installation decrease and its net power increases.

In Fig. 2 dotted line showed dependence $З_э = f(\sigma)$ when $\bar{C}_т = 0.20$ with greater cost/value of reactor plant $K_p' = 1.5\ K_p$. The optimum parameters in this case do not change, grows/rises only cost/value 1 kW·h of electric power (almost by 30%).

Fig. 3 shows change $З_э$, $\eta^{эл}$, $N^{эл}$, q and $t_{пв}^{опт}$ in dependence on σ also with G = const but at heat output of reactor $N_т = 2000$ MW. In this case optimum values σ decrease to 1.855-1.880 $(\bar{C}_т = 0.00 \div 0.40)$, and $t_{пв}$ grow/rise to 117-128°C. Are displaced in the direction of smaller values σ the maximum of electrical plant capacity $(N^{эл} = 852$ kW when σ = 1.875) and the minimum of specific capital investments (q = 134.5

rub/kW with σ = 1.87). Cost/value 1 kW·h of electric power - from 0.345 ($\bar{C}_т = 0.00$) to 0.620 kopecks ($C_т = 0.40$).

Fig. 4 shows the same dependences, but under condition of constant power of reactor ($N_p = 500$ MW) and with variable/alternating flow of gas (G = var). The obtained results, as is evident in Fig. 4, sharply they differ from preceding/previous (Fig. 2). Optimum pressure ratio in this case composes 1.78-1.80, while the optimum temperature of feed water - 158-165°C. Cost/value 1 kW·h of electric power depending on $\bar{C}_т$ varies within the limits of 0.427-0.773 kopecks, and specific capital investments - 166.5-167.5 rub/kW. Since for the base value the parameters of the absolute extremes were accepted, then the maximum of power (and efficiency) lies/rests with σ = 1.75 and $t_{пв} = 182$°C and is $N^{сг}$ = 206 MW.

More worse/worst specific economic indices of steam-gas installation during its calculation with N = const (G = var) are explained by the fact that with change values σ against extreme efficiency and power of steam-gas installation descend. With the decrease σ (against the extreme) a decrease in the power of steam-gas installation occurs due to the gas-turbine part, while with an increase σ - steam-powered.

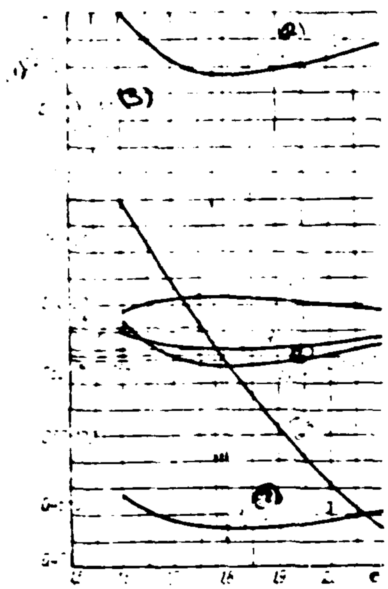

Fig. 4. Definition/determination of optimum parameters $(\sigma_{опт}, \rho_{пр}^{опт})$ when N_{Γ} = const (500 MW when $\sigma_{ПКС}$ = 1.75)

Key: (1). (kop/kW·h). (2). with. (3). MW.

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Conclusions.

1. Definition/determination of optimum parameters of atomic steam-gas installation is recommended to produce with G = const and

$N_p = var.$ since best technical-economic indices of installation correspond to this case.

2) With increase in power of atomic steam-gas installation, together with improvement in economic indices, optimum pressure ratio descends and optimum temperature of feed water increases.

3) Increase in propellant/fuel component leads to decrease of optimum pressure ratio and to increase in temperature of feed water. Within limits $\bar{C}_T = 0{,}00$—$0{,}40$ optimum value σ varies within the limits of 1.0-1.5% (abs.).

4) Change of cost/value of reactor plant over wide limits virtually does not have effect on numerical values of optimum parameters ($\sigma_{опт}$, $t_{пв}^{опт}$, $\tau_{опт}$) being investigated

5) In all cases optimum pressure ratio is more, and temperature of feed water is less than outer limits, obtained by thermodynamic calculations.

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