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ANALYSIS OF METHODS FOR INCREASING THE EFFICIENCY OF GAS TURBINE UNIT OPERATION

Introduction

At present, gas turbine technology are widely used both in our country and abroad as ground power plants. Power plants are complex technical objects that combine the latest achievements and the latest developments in many branches of science and technology, at the same time possessing high efficiency and the required performance characteristics for various consumers.

A promising direction in the development of the energy sector is the use of energy-saving technologies based on gas turbine plants (GTP), which makes it possible to increase the efficiency of using fossil fuel. In some cases, the operation of the gas turbine plant is carried out at modes below the optimum in terms of efficiency; therefore, economic efficiency of the plant as a whole is a great interesting. This determines a large number of constantly implemented in practice, possible schemes and ways to improve GTP based on gas turbine engines.

To increase effective efficiency and work, it is necessary to ensure the highest possible temperature in front of the turbine. The high temperature in front of the turbine, in addition to directly increasing the cycle work, allows a higher pressure ratio to be applied. This direction of improving the simple cycle is limited by the technological capabilities available at a given time.

The development of engines with complex thermodynamic cycles is one of the promising trends. At present, converted aircraft engines are widely used all over the world, while it is possible to use structural elements of basic gas turbine engines, as well as to create new promising aircraft gas turbine units and combined power plants for various purposes. For ground-based gas turbines operating at modes close to maximum, the most important requirement is the minimum possible fuel consumption, and the weight and dimensions of such units are not so important. The complex GTU cycle contains additional thermodynamic processes that are not included in the simple cycle:

- reheating during expansion;
- intermediate cooling during compression,
- utilization of exhaust gas heat,
- humidification of cycle air, etc.

In order to select the more efficient modifications, all these cycles must be compared together using a full and accurate calculation. Different modifications in the gas turbine engine have to be quantified at different temperatures in front of the turbine and compressor pressure ratio within their practical ranges.

The aim of the work

The aim of this work is analysis of the ways to increase the thermal efficiency of power gas turbine plants by improving their thermal and technological schemes, selection and optimization of the most promising schemes.

Analysis of recent research and publications

Zysin V., Andryushchenko A., Tsanev S., Okhotin V. and others made a great contribution to the study of the efficiency of gas turbine plants and ways to improve it, as well as the creation of methods for calculating such plants.

The analysis of the current level of development of gas turbine technologies is carried out in works [1; 2]. It is shown that today, to create a highly efficient and reliable gas turbine drive, it is advisable to use a scheme with waste gas heat recovery. Such scheme makes it possible to obtain high values of efficiency at moderate values of pressure ratio in the compressor and the gas temperature at the turbine inlet. The prospect of this direction are confirmed by the results of works [3; 4; 5]. Specific attention was paid to improving efficiency of power gas turbine units in works [6; 7; 8].

The search for directions for increasing the efficiency of gas turbines is the main task of their further development. In [9; 10], various methods, parameters and goals of optimization of gas turbine cycles are described.

Publications [11; 12] are devoted to the theoretical optimization of complex thermodynamic cycles of gas turbines according to new criteria and for fairly wide parameters of the plant operation. The author theoretically substantiated the efficiency of using complex cycles of GTU with intermediate cooling, heating and heat recovery of exhaust gases.

In all the works discussed above, the importance of optimizing the GTU cycles was noted, since the deviation of the main parameters of the cycles from the optimal ones significantly affects the efficiency of the cycle.

It is necessary to begin a wider implementation of the development of promising gas turbine units of a complex scheme: with heat recovery; with intermediate air cooling in the compressor; with heat recovery and intermediate air cooling in the compressor.

Based on the foregoing, work on improving gas turbine schemes and optimizing their parameters is relevant.

Problem statement

The possibility of using classical methods for increasing the efficiency of a stationary gas turbine based on an aircraft engine of a simple scheme has been investigated (Fig. 1).

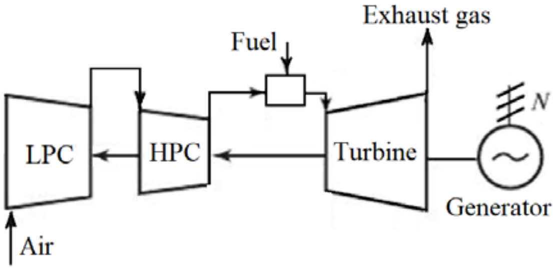

Fig. 1. A scheme of a gas turbine unit simple cycle

Two schemes of complex cycles are considered. The complication of the scheme occurred in two stages: the use of two-stage compression with intercooling (Fig. 2), the combined using of two-stage compression with intercooling and regeneration (Fig. 3).

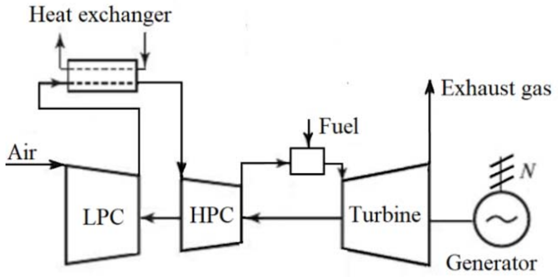

Fig. 2. A scheme of a gas turbine unit with intercooling

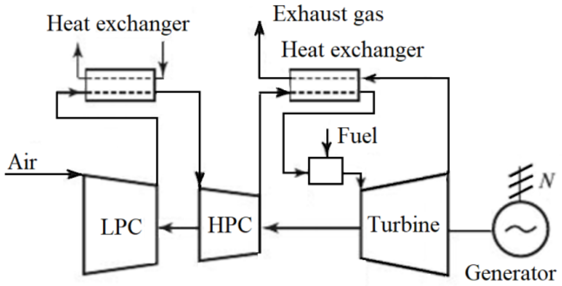

Fig. 3. A scheme of a gas turbine unit with intercooling and regeneration

In this work, a comparative analysis of the efficiency of simple and complex gas turbine cycles was carried out. The criterion of optimality was the effective efficiency of the gas turbine unit.

The *T–s* diagram of an actual thermodynamic cycle carried out by the working fluid of the GTU is shown in Fig. 4. A real gas turbine unit operates in an irreversible cycle, in which all processes occurring in the gas turbine unit are completely irreversible and are accompanied by energy losses. For such cycle, all parameters of the working fluid are selected as the most economically advantageous. In addition, the requirements for environmental friendliness and reliability of the installation must be ensured.

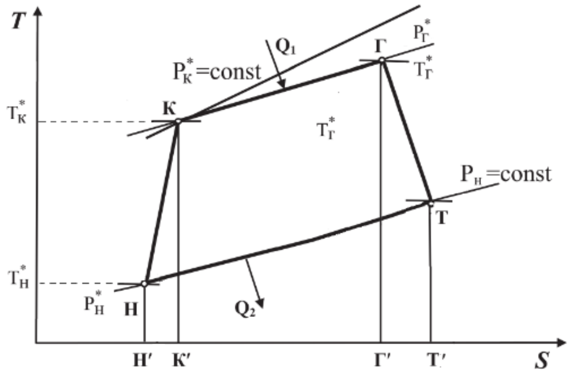

Fig. 4. *T–s* diagram of an actual cycle of gas turbine unit

The main parameters of a gas turbine unit cycle are the degree of heating of the working fluid in the cycle

$$\Delta = T_{\text{г}}/T_{\text{н}}$$

and the total pressure ratio

$$\pi = p_{\text{к}}/p_{\text{н}},$$

where $T_{\text{г}}$ — the gas temperature in front of the turbine; $T_{\text{н}}$ — the temperature of the outside air before entering into compressor, $p_{\text{к}}$ — the pressure behind the compressor, $p_{\text{н}}$ — the pressure of the outside air.

The selection and optimization of these basic cycle parameters are the main part of the thermodynamic calculation of a complex cycle gas turbine unit. To select a method to increase the efficiency of a gas turbine unit, a thermodynamic analysis of the influence of the parameters of the operating process of a gas turbine unit on the efficiency and specific power was carried out. This makes it possible to reasonably choose the optimal combination of parameters, determine their maximum value, and objectively compare various thermal schemes according to their energy parameters, which is a very urgent task.

Performance analysis of the cycles

The specific useful work of the theoretical cycle is always greater than the actual useful work; therefore, the effective efficiency of the engine η_{e} is less than the thermal efficiency of the cycle η_{th}.

$$\eta_e = L_{\text{e}}/\text{q}1,$$

where L_{e} is the effective work of the actual cycle; q_1 is the specific heat supplied in the cycle.

The work of the actual cycle of the gas turbine is defined as the difference between the actual work of expansion in the turbine and compression in the compressor [13]:

$$L_{\text{e}} = \frac{k}{k-1} R T_{\text{н}} \frac{e-1}{\eta_{\text{c}}} \left(\frac{\bar{m} \Delta \eta_{\text{c}} \eta_t}{e} - 1 \right),$$

where k — the adiabatic index for air; R — the gas constant of air; $T_{\text{н}}$ — outside air temperature; η_{c} and η_t coefficients of efficiency, taking into account hydraulic losses in the processes of compression and expansion, $e = \pi k - 1/k$; $T_{\text{г}}$ — the gas temperature in front of the turbine; $\Delta = T_{\text{г}}/T_{\text{н}}$; $\bar{m}$ — coefficient taking into account the difference in the physical properties of air and combustion products

$$\bar{m} = \frac{\left\| \frac{k_g}{k_g - 1} R_{\text{g}} \left(1 - \frac{1}{\pi_t^{\frac{k_g}{k_g - 1}}} \right) \right\|}{\frac{k}{k-1} R \left(1 - \frac{1}{\pi^{\frac{k}{k-1}}} \right)},$$

where π_t is the pressure ratio in the turbine ($\pi_{\text{p}} \approx \pi$); k_{g} — gas adiabatic index; R_g — gas constant of combustion products.

The effective specific work of a simple cycle gas turbine with a free turbine is equal to the work of a free turbine $L_e = L_{ft}$ [14]:

$$L_e = c_{pg} T_{tc} \left(1 - \frac{1}{e_{ft}} \right) \eta_{ft},$$

where T_{tc} is the gas temperature behind the compressor turbine; cpg is specific heat of gas (combustion products) at constant pressure; η_{ft} is the efficiency of a free turbine; $e_{ft} = \pi_{ft}\ (k - 1)/\text{k}$; π_{ft} is the pressure ratio in the free turbine.

Gas temperature behind the compressor turbine:

$$T_{tc} = T_{\text{г}} \left(1 - \frac{1}{e_{tc}} \right) \eta_{tc},$$

where η_{tc} — efficiency of compressor turbine; etc is the pressure ratio of gas in the compressor turbine,

$$e_{tc} = \frac{1}{1 - \frac{e-1}{\Delta \eta_c \eta_{tc}}}.$$

Substituting the obtained expression for the parameter Ttc into the formula for determining the effective specific work, we write:

$$L_e = c_{pg} T_{\text{г}} \left(1 - \frac{e-1}{\Delta \eta_c} \right) \left(1 - \frac{1}{e_{ft}} \right).$$

The resulting expression contains the ambient temperature $T_{\text{н}}$, since $\Delta = T_{\text{г}}/T_{\text{н}}$. Turning to the relative dimensionless work of the cycle, it is possible to exclude the influence of $T_{\text{н}}$, referring the amount of work to the enthalpy of atmospheric air.

In dimensionless form, the actual work of the cycle is:

$$\bar{L}_e = L_e / \left(c_{pg} T_{\text{н}} \right);$$

$$\bar{L}_e = \Delta \left(1 - \frac{e-1}{\Delta \eta_{\text{c}}} \right) \left(1 - \frac{1}{e_{ft}} \right) \eta_{\text{ft}}.$$

Specific heat input

$$q_1 = c_{pc} T_{\text{н}} \left[\Delta - \frac{(e-1)}{\eta_c} - 1 \right] \Big/ \eta_f,$$

where η_f is the fuel combustion efficiency, cpc is the conditional specific heat of heat supply process in the combustion chamber.

Relative heat input

$$\bar{q}_1 = q_1 / \left(c_{\text{ср}} T_{\text{н}} \right).$$

The effective efficiency of a simple cycle GTU with a free turbine is written according to [15]:

$$\eta_e = \frac{\Delta\left(1 - \frac{e-1}{\Delta\eta_c}\right)\left(1 - \frac{e_{tc}}{e}\right)\eta_{ft}}{\Delta - \frac{e-1}{\eta_c} - 1}.$$

The parameters of a gas turbine cycle with a free turbine located on a separate shaft behind the gas generator were analyzed. In the GTU scheme, the turbine module includes a compressor turbine and an uncooled power turbine. Since the power turbine is uncooled, the temperature in front of the power turbine should not exceed 1250 K, and the gas temperature in front of the compressor turbine should not exceed 1800 K.

In order to conduct a numerical study to optimize the parameters of the gas turbine unit, the parameters AI–336–1/2–10 were taken. The characteristics of the GTU cycles were determined from the values of π and $T_г$. For the analysis of the cycles, the following parameter values were chosen: π in the range 10 – 45; $T_г$ = 1300 K.

Losses due to the irreversibility of compression in the compressor and expansion in the turbine were taken into account by the internal relative efficiency of the compressor (η_c = 0,85) and the turbine (η_t = 0,9). Below are the results of the study.

The most important parameter that determines the perfection of the cycle and the GTU as a whole as a heat engine is the gas temperature in front of the turbine. Fig. 5 shows the dependences of the effective efficiency of the unit on the gas temperature $T_г$ and the pressure ratio π. Increase the pressure ratio increases the effective efficiency at a given temperature $T_г$, but increase the pressure ratio at any given temperature $T_г$ can reduce the overall cycle efficiency.

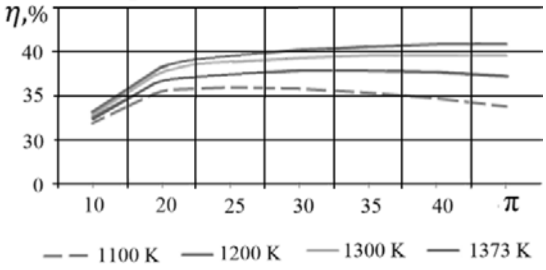

Fig. 5. Influence of the gas temperature in front of the turbine on the efficiency of the gas turbine

It can be seen from Fig. 5 that a high effective efficiency (> 40 %) can be obtained in a gas turbine engine of a simple scheme, and its further increase is possible only at very high cycle parameters (π > 20 and $T_г$ > 1400 K).

Fig. 6 shows the combined effect of the pressure ratio and temperature of the gas in front of the turbine on the cycle work.

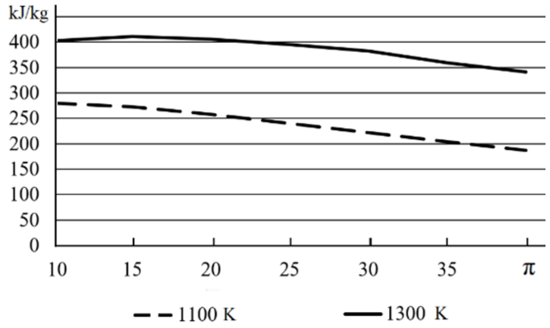

Fig. 6. The influence of the pressure ratio and gas temperature in front of the turbine on the cycle work

As can be observed from Fig. 5 and Fig. 6, the increasing of temperature $T_г$, the specific work of the cycle increases and the effective efficiency increases. For each temperature $T_г$, there is an optimal value of the compressor pressure ratio corresponding to the maximum specific work. However, at the same temperature, the maximum efficiency is achieved at a higher pressure ratio, therefore the optimum pressure ratio in terms of efficiency is significantly higher than the optimum pressure ratio in terms of specific work: $\pi_{opt}\,\pi_e > \pi_{opt}\,L_e$. The deviation of the basic parameters from the optimal ones significantly affects the cycle efficiency. Therefore, important to optimize the cycle in order to obtain maximum efficiency, and therefore minimum fuel consumption. When optimizing the main parameters, an intermediate value of pressure ratio is selected, between the optimal pressure ratio in terms of work and the optimal pressure ratio in terms of efficiency.

An increase in π and Δ requires a greater increase in the compressor power in comparison with an increase in the effective work and effective efficiency of the GTU as a whole. By increasing the values of π and Δ (see Fig. 5, 6), we obtain a significant increase in the energy efficiency of the gas turbine, but at the same time the difference ($\pi_{opt}\,\pi_e - \pi_{opt}\,L_e$) also increases, and, accordingly, the range of choice of cycle parameters π and Δ.

Fig. 7 shows the effect of pressure ratio and temperature at the turbine inlet on the specific fuel consumption.

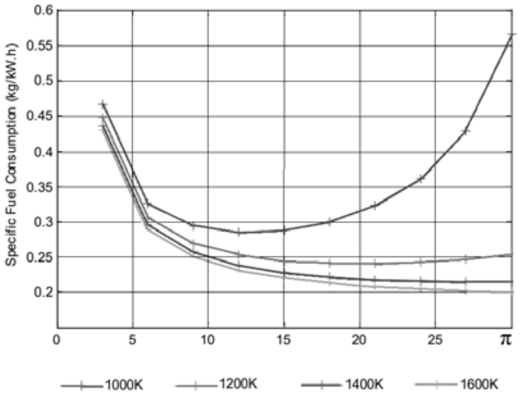

Fig. 7. Effect of pressure ratio and turbine inlet temperature on specific fuel consumption

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The influence of the compressor pressure ratio on the main characteristics of the turbine was evaluated. Fig. 8 shows the dependence of the power of the turbine and the temperature of the gases behind the turbine on the compressor pressure ratio.

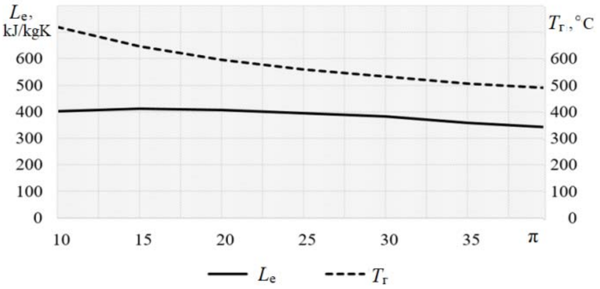

Fig. 8. Influence of pressure ratio on the power of the GTU and the gas temperature behind the gas turbine

It is noticed that the specific fuel consumption decreases with an increase in turbine inlet temperature and compressor pressure ratio in a lower range of π to a certain value, and then sharply increases at a lower temperature at the turbine inlet. Based on this, the gas temperature in front of the turbine in this study is 1300 K.

Fig. 9 shows the dependence of the parameters of a gas turbine with a free turbine on the pressure ratio at the maximum cycle temperature $T_г$ = 1300K.

The analysis of the obtained dependencies (Fig. 9) shows that the value of the optimal value of pressure ratio in terms of effective efficiency is greater than the optimal value of pressure ratio in terms of specific effective work. Therefore, the value of pressure ratio is chosen in the range of values $\pi_{opt}\, L_e \div \pi_{opt}\, \pi_e$ so as to obtain work close to maximum and possibly high effective efficiency.

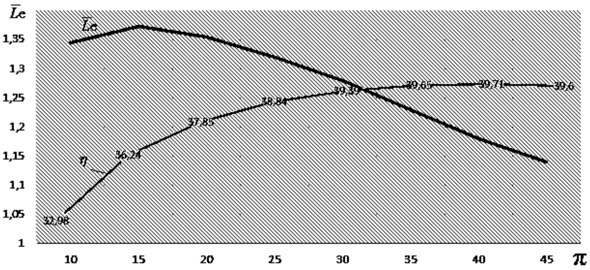

Fig. 9. Dependence of the relative cycle work and the effective efficiency on the pressure ratio

With an increase in the pressure ratio from the optimal value for the effective cycle work (π = 15) to the optimal value of the pressure ratio for the effective efficiency (π = 40), the degree of relative increase in the effective efficiency is 0,38 %, which is less than the relative degree of decrease in the cycle work, which is 0,58 %.

The gentle nature of the change in the efficiency in the region of the maximum makes it possible to reduce the calculated pressure ratio of air in the compressor, which greatly facilitates the gas turbine unit design.

Cycle with two-stage compression and intercooling

Energy, economic and environmental characteristics largely depend on the configuration of the thermodynamic cycle and the organization of its processes. The efficiency of a simple cycle GTU can be increased by reducing the power consumed by the compressor. This is possible if the compression process is made in two stages with intermediate air cooling during the compression process.

The work required to run the compressor is expressed as:

$$L_{cycle,inc} = L_{\text{c}1} + L_{\text{c}2}\,,$$

where $L_{\text{c}1}, L_{\text{c}2}$ — compression work of first and second compressor stages.

$$L_{cycle,inc} = 2c_{\text{p}}T_{\text{í}}\left(\pi_{\text{ñ}}^{\frac{k-1}{2k}} - 1\right)\eta_{\text{c}}\,.$$

The optimal value of the pressure ratio π_{opt}, at which the maximum specific power is reached at a given degree of heating of the working fluid Δ (i.e., at a given initial temperature) can be determined from the ratio [16]:

$$\pi_{\text{opt}} = \Delta^{\frac{2k}{3(k-1)}}\,.$$

Specific work of a complex cycle gas turbine

$$L = \eta_{\text{t}}\frac{k_{\text{g}}}{k_{\text{g}}-1}R_{\text{g}}T_{\text{г}}\left(1 - \frac{1}{\pi^{\frac{k_{\text{g}}-1}{k_{\text{g}}}}}\right) - \\ - \frac{2k}{\eta_{\text{c}}(k-1)}RT_{\text{н}}\left(\pi^{\frac{k-1}{zk}} - 1\right).$$

The heat input into the cycle $q_{1\text{inc}}$ is

$$q_{1inc} = c_{\text{pc}}\left(T_{\text{г}} - T_{\text{к}}\right)/\,\eta_{\text{f}}\,,$$

where $T_к$

$$T_{\text{к}} = T_{\text{н}}\left(1 + \frac{\pi^{\frac{k-1}{2k}} - 1}{\eta_{\text{c}}}\right).$$

Efficiency of a gas turbine unit with intercooling

$$\eta_{einc} = L_t\frac{\eta_t - \left(\frac{L_{\text{c}1}}{\eta_{\text{c}1}} + \frac{L_{\text{c}2}}{\eta_{\text{c}2}}\right)}{q_{1inc}}\,,$$

where L_t — the useful work of the gas turbine, equal to the difference between the work of the turbine and the work of the compressors of the first and second stages of compression; q_{1inc} — the specific heat consumption in the combustion chamber; η_{c1}, η_{c2} — coefficients of efficiency, taking into account hydraulic losses in the compression processes in first and second stage.

The results of the calculations are shown in Fig. 10–13. Fig. 10 shows the changes in the relative dimensionless work, effective cycle efficiency and heat input with the pressure ratio increase. The value of pressure ratio at which the maximum work reached at a given degree of working fluid heating (Δ = 4,6) increases compared to the optimal pressure ratio in the base cycle.

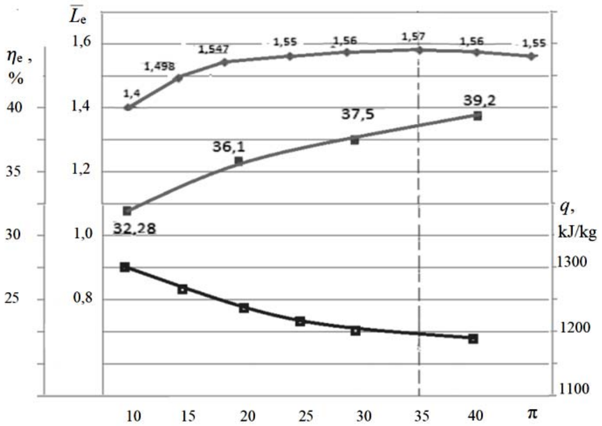

Fig. 10. Thermal efficiency, power output and heat supplied versus the pressure ratio

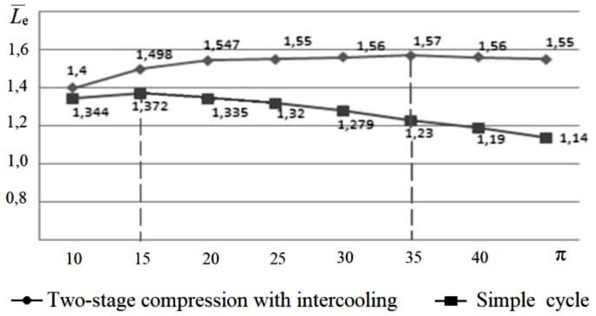

Fig. 11. Dependence of relative work of a simple Brayton cycle and a cycle with intercooling on the degree of pressure increase for Δ = 4,6

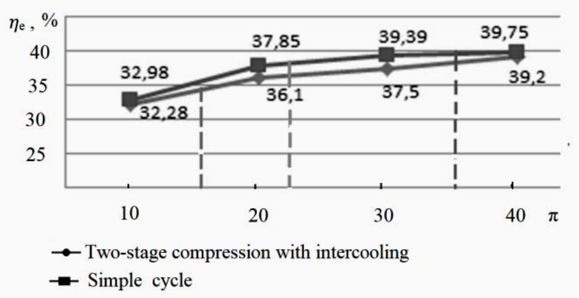

Fig. 12. Dependence of the efficiency of a simple Brayton cycle and a cycle with intercooling on the pressure ratio for Δ = 4,6.

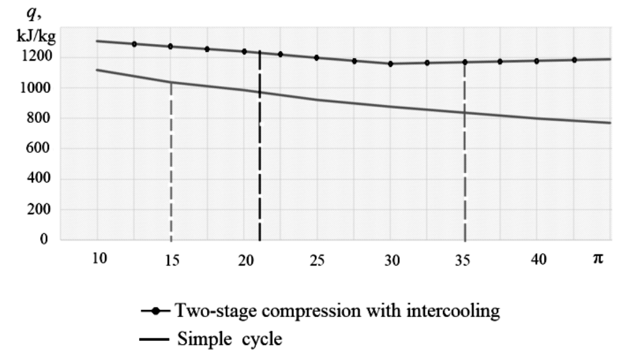

Fig. 13. Dependence of the supplied heat in a simple Brayton cycle and a cycle with intermediate cooling on the pressure ratio for Δ = 4,6

The dependences of the relative dimensionless work of the cycle versus the pressure ratio for the base cycle and the cycle with intercooling is shown in Fig. 10.

The pressure ratio for maximum power is 35 in the cycle with intercooling. The power output increases by 27,5 % compared to power in the base cycle.

The analysis showed that the using of two-stage compression and intercooling results in:

– an increase in the specific power of the gas turbine plant; with an increase in pressure ratio up to π = 40, the increase in the specific power reaches 15–30 %;

– a decrease in the efficiency of the cycle from 0,5 to 1,9 %, depending on the pressure ratio; the decrease in efficiency is associated with a decrease in the temperature of the compressed air in front of the combustion chamber;

– an increase in fuel consumption up to 19 %.

From the point of view of economy, the use of intercooling in the scheme of a gas turbine plant is ineffective.

GTU with intermediate air cooling and regeneration of heat

The introduction of regeneration into the gas turbine unit reduces the negative effect of air cooling during the compression process since a significant part of the additional heat can be transferred to the air in the regenerator [17].

The possibility of increasing the efficiency of the unit due to heat recovery is shown in Fig. 14, and the change in efficiency depending on the degree of regeneration is shown in Fig. 15 [18].

It can be seen that at a gas temperature of 1550 K π^*=10 and the degree of regeneration 0,85 the efficiency can reach 42,5%.

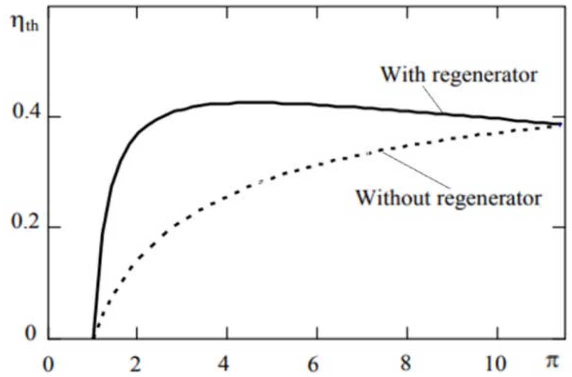

Fig. 14. Effect of pressure ratio on thermal efficiency for simple and regenerative cycle

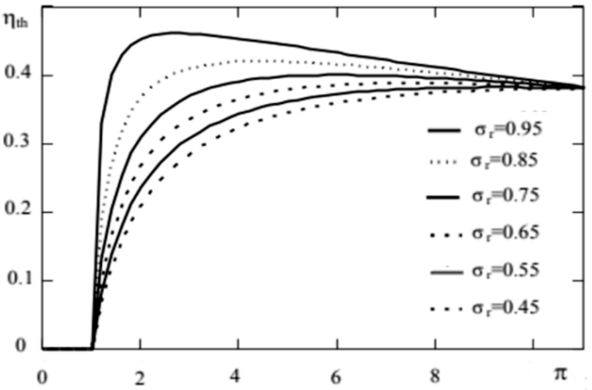

Fig. 15. Variation of thermal efficiency on pressure ratio and regenerative effectiveness

It can be seen from Fig. 15 that with an increase of pressure ratio π, the efficiency of the GTU with heat recovery decreases, in contrast to the efficiency of the GTU of a simple cycle. The optimal values of the pressure ratio in the cycle with heat recovery of exhaust gases are less than in the cycle without heat recovery.

The higher the degree of regeneration σ_{reg}, the less $q_{1\text{reg}}$ and the higher the efficiency of the cycle. With an increase in the degree of heat regeneration the pressure ratio optimal in terms of effective efficiency decreases.

The efficiency of the engine itself decreases with a pressure ratio decrease; the efficiency of regeneration increases significantly. Thus, two opposing factors affect the efficiency of the GTU with heat recovery.

Therefore, for a gas turbine unit with heat recovery, it is necessary to optimize the pressure ratio π and the temperature of the gas $T_{\text{г}}$ [6].

The expressions for the operation of the turbine, compressor and the entire gas turbine unit will remain unchanged.

The use of regeneration increases the efficiency of the cycle, since the regeneration does not change the value of the specific work of the cycle, but reduces the amount of heat input. Efficiency of the plant with regeneration:

$$\eta_e^r = \frac{L_{cycle}}{q_{1\text{r}}} = \frac{\left[c_{\text{p}} T_{\text{н}} (e-1)\left(\frac{\bar{m}\Delta\eta_{\text{c}}\eta_{\text{t}}}{e} - 1\right)/\eta_{\text{c}}\right]}{c_{\text{pc}}\left(T_{\text{г}} - T_5\right)/\eta_{\text{f}}},$$

where T_5 is the actual gas temperature downstream of the regenerator:

$$T_5 = T_{\text{к}} + \sigma_{\text{reg}}(T_{\text{т}} - T_{\text{к}}).$$

The efficiency of the GTU with regeneration depends on the compressor pressure ratio, the initial cycle temperature, and the degree of regeneration σ_{reg}. An increase in the degree of regeneration σ_{reg} increases the efficiency of the unit, but also the specific surface area of the regenerator and, consequently, its cost.

The use of a regenerator in a gas turbine unit with intermediate air cooling provides a significant gain in cycle efficiency.

As a result, the heat supplied to the cycle decreases due to the influence of the regenerator and changes little over a wide range of parameter variation, and the useful work of the cycle increases due to intermediate cooling (Fig. 16).

The increase in efficiency in a cycle with intercooling and a regenerator is shown in Fig. 17.

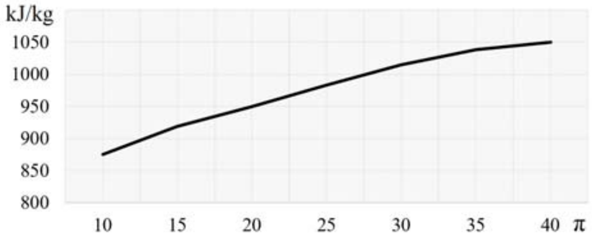

Fig. 16. Useful work of the cycle with air cooling and regeneration of heat versus pressure ratio

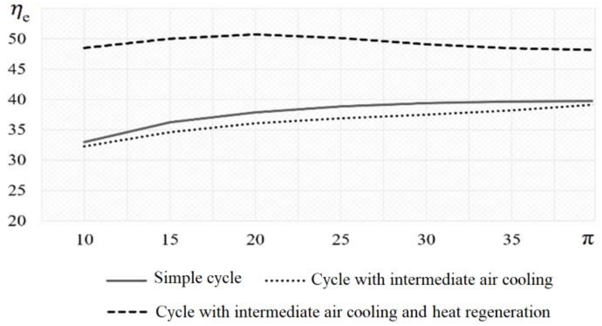

Fig. 17. Efficiency of the cycle versus pressure ratio

As follows from the Fig. 17, the efficiency increment is 8...14 %, and the optimal value of π is shifted to the left, to the region of lower values, which also simplifies the choice of parameters and the design of the unit.

Conclusions

The study of the effect of heat regeneration and intermediate cooling of the working fluid on the effective efficiency of the gas turbine unit was carried out.

In a gas turbine plant of a simple scheme, a high effective efficiency can be obtained and its further increase is possible only at cycle parameters $\pi > 20$ and $T_{\text{г}} > 1400$ K. With an increase in the pressure ratio, the effective efficiency increases the more, the higher the temperature $T_{\text{г}}$. In this case, the value of the optimal pressure ratio in terms of effective efficiency is greater than the optimal pressure ratio in terms of specific effective work. To obtain work close to maximum and possibly high effective efficiency, the pressure ratio is selected in the range of values πopt $L_e \div \pi_{opt}\,\pi_e$ closer to $\pi_{opt}\,L_e$.

It is possible to increase the efficiency of a simple cycle GTU by reducing the work of compression of the working fluid, i.e. make the compression process two–stage with intermediate air cooling.

In a GTU with heat recovery, with a decrease in π, the effective efficiency of the original engine (without regeneration) decreases, and the efficiency of the regeneration itself increases significantly.

Due to multistage compression with intercooling and exhaust gas regeneration it is possible to achieve high values of effective efficiency (η_e = 49 %) at pressure ratio $\pi < 20$ and maximum gas temperature $T_{\text{г}} = 1300$ K, such efficiency values for a GTU of a simple scheme can be obtained only at high cycle parameter π = 30–60 and $T_{\text{г}} > 1400$ K.

Optimal values of the pressure ratio in the thermodynamic cycle of a gas turbine unit with two-stage compression, intercooling, and heat recovery are 2–3 times less than in a simple scheme engine.

Based on the performed computational analysis, it has been established that the most preferable GTU scheme is a scheme with two–stage compression, intermediate cooling and heat recovery.

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АНАЛІЗ МЕТОДІВ ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ РОБОТИ ГАЗОТУРБІННОЇ УСТАНОВКИ

Перспективним напрямком розвитку енергетики є застосування енергозберігаючих технологій на базі газотурбінних установок, що дозволяють істотно підвищити ефективність використання органічного палива. Одним з перспективних способів поліпшення паливної ефективності газотурбінних установок є застосування складних термодинамічних циклів. У статті наведено дослідження підвищення економічності газотурбінних установок шляхом удосконалення їх теплових і технологічних схем.

Розглянуто схеми з проміжним охолодженням в процесі стискування повітря і з регенерацією тепла вихлопних газів. У статті розглядається задача оптимізації та вибору раціональних параметрів робочого процесу газотурбінної установки. Комплексна оптимізація параметрів термодинамічного циклу газотурбінної установки, таких як температура газу перед турбіною, ступінь підвищення тиску в компресорі, а також параметрів, що визначають робочий процес додаткових вузлів установки грає важливу роль для підвищення її ефективності.

Як об'єкт дослідження було обрано газотурбінний привід АІ–336–1/2–10, призначений для приводу газоперекачувальних агрегатів та інших промислових установок потужністю 10 МВт.

Вибір параметрів робочого процесу, що забезпечують максимальну ефективність, є основним завданням при проектуванні двигунів зі складними циклами.

Наведено результати чисельного дослідження впливу основних параметрів робочого процесу установки на ефективність, проаналізовано вплив ступеня підвищення тиску і максимальної температури циклу на параметри циклу.

Проведено порівняння значень оптимального ступеня підвищення тиску та ефективного ККД з оптимальним ступенем підвищення тиску за питомою ефективною роботою для циклів простої схеми і складного.

Показано, що за рахунок багатоступінчастого стискування з проміжним охолодженням і регенерацією вихлопних газів можна досягти високих значень ефективного ККД, які для газотурбінної установки простої схеми можна отримати тільки при високих параметрах циклу.

Ключові слова: газова турбіна; підвищення ефективності; утилізація тепла; регенерація; охолодження повітря.

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ANALYSIS OF METHODS FOR INCREASING THE EFFICIENCY OF GAS TURBINE UNIT OPERATION

A promising direction in the development of the energy sector is the use of energy–saving technologies based on gas turbine units, which can significantly increase the efficiency of fossil fuel use. One of the promising ways to improve the fuel efficiency of gas turbine plants is the use of complex thermodynamic cycles. The article presents a study of increasing the efficiency of gas turbine plants by improving their thermal and technological schemes. The schemes with intermediate cooling in the process of air compression and with heat recovery of exhaust gases are considered. The article discusses the problem of optimization and selection of rational parameters of the working process of a gas turbine plant. Integrated optimization of the parameters of the thermodynamic cycle of a gas turbine unit, such as the gas temperature in front of the turbine, compressor pressure ratio, as well as the parameters that determine the working process of additional units of the plant, plays an important role in increasing its efficiency. The AI–336–1 / 2–

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10 gas turbine drive, designed to drive gas–pumping units and other industrial plants with a capacity of 10 MW, was chosen as the object of the study.

Selecting workflow parameters that provide maximum efficiency is a major challenge in the design of complex cycle motors.

The results of a numerical study of the influence of the main parameters of the operating process of the plant on the efficiency are presented, the influence of pressure ratio and the maximum cycle temperature on the cycle parameters is analyzed.

The comparison of the values of the optimal pressure ratio in terms of effective efficiency with the optimal pressure ratio in terms of specific effective work for cycles of a simple scheme and a complex one.

It is shown that due to multistage compression with intercooling and exhaust gas regeneration; it is possible to achieve high values of effective efficiency, which for a gas turbine plant of a simple scheme can be obtained only at high cycle parameters.

Keywords: gas turbine; efficiency increase; heat utilization; regeneration; cooling of air.

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