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Effect of Heat Regeneration in Gas Turbine Plants with Izobaric and Isochoric Heat Supply

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ABSTRACT
Considered jointly thermodynamic cycles of gas turbine plants with isobaric and isochoric heat supply: simple and using regenerative heating of air supplied to the combustion chamber. The comparative calculations have shown that a cycle with isochoric supply and heat regeneration is much more efficient than the corresponding basic cycle with isobaric heat supply without regeneration. Thus, in cycle with isochoric heat supply and regeneration with reduced amount of heat input by 47.3%, the specific power of the gas turbine plant increases by 9.9% and the thermal efficiency by 15.2%, compared with the base cycle.

KEYWORDS
Gas turbine plant. Thermodynamic cycle. Isobaric and isochoric heat supply. Heat regeneration.

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I. INTRODUCTION

The problem of increasing the efficiency of converting heat into work by power plants was and always will be relevant. The works [1-6] consider the issue of increasing the efficiency energy installations, but the use of regenerative heat exchange between the exhaust gases and the air supplied to the combustion chamber is not analyzed.

This work compares simple GTP cycles with isobaric and isochoric heat supply and their modifications with heat regeneration. Quantification relative the efficiency of the compared cycles is the goal of the work. This is done by comparative calculations and analysis of the values characterizing the effectiveness of the compared cycles. This analysis also allows us to propose a way to reduce the main disadvantage of gas turbines – the comparability of the work of gas expansion in the turbine and the work of air compression in the compressor. The smaller this ratio, the more "pure" mechanical energy is obtained from used working gas turbine.

Investigation of problem

On fig. 1 and 2 in the coordinates *p,v* and *T,s* are shown jointly compared thermodynamic cycles of gas turbine plants: 1-2-3-4-1 – classic cycle GTP with isobaric heat supply without regeneration;1-2-5-3-4-6-1 – cycle with isobaric supply and heat regeneration of exhaust gases; 1-2′-3-4-1 – cycle with isochoric heat supply without regeneration; finally, 1-2′-6′-3′-4′-5′-1 is a cycle with isochoric supply and heat regeneration. The listed cycles have the same parameters of the air sucked in by the compressor and the same temperature of the gas entering the turbine blades.

On fig. 3 is shown a schematic diagram of heat recovery installations. Schematic diagrams of installations without regeneration differ from the shown by the absence of regenerative heat exchangers ***IX***. The principle of operation of the compared gas turbine plants is clear from the joint consideration of their cycles and the schematic diagram, taking into account the figure captions.

To quantitatively evaluate the efficiency of the considered variants of the GTP thermodynamic cycle, their thermal calculations were performed provided that the temperature and pressure of atmospheric air are equal to 30 °C and 0.101325 MPa, the degree of air pressure increase in the compressor is $\beta = 7$, and the temperature of the gases supplied to the turbine blades is 850 °C. The specified temperature value is selected from the condition of maintaining the strength of the turbine blades.

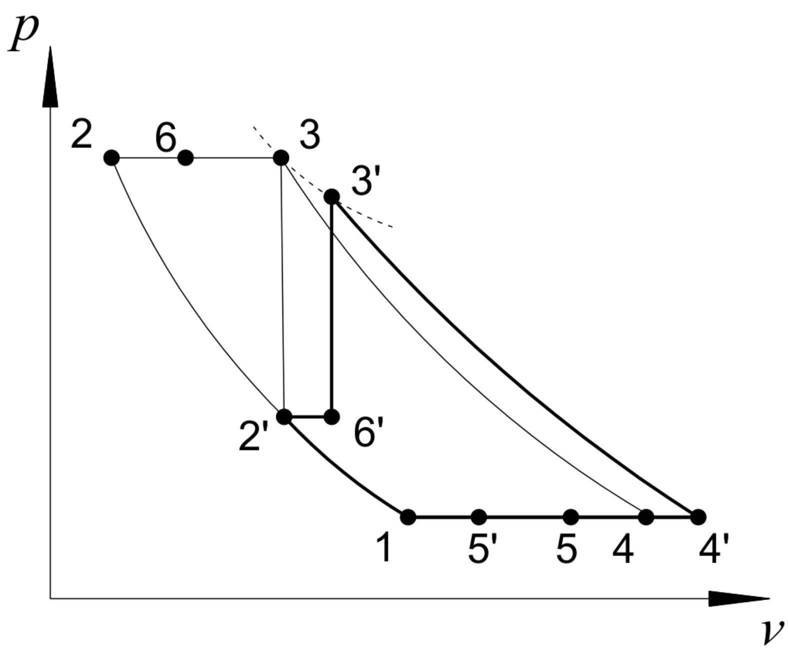

Figure 1. Comparison in coordinates p,v of GTP thermodynamic cycles: basic with isobaric heat supply without regeneration 1-2-3-4-1 and modified: 1-2-5-3-4-6-1 – with isobaric supply and heat regeneration; 1-2′-3-4-1 – with isochoric heat supply without regeneration; and 1-2′-6′-3′-4′-5′-1 - with isochoric supply and heat regeneration

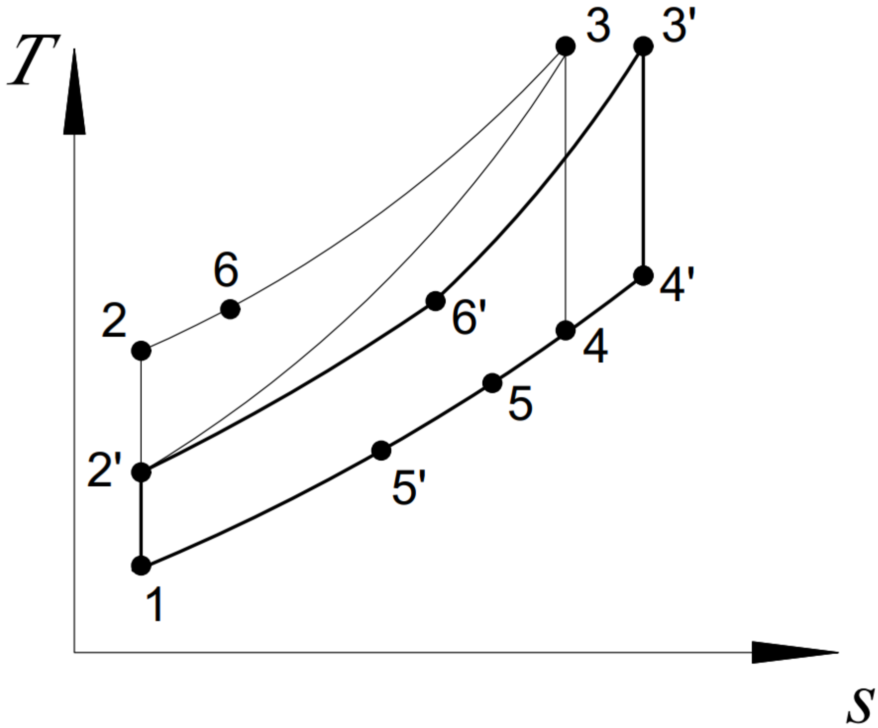

Figure 2. Comparison in coordinates T,s of GTP thermodynamic cycles: basic with isobaric heat supply without regeneration 1-2-3-4-1 and modified: 1-2-5-3-4-6-1 – with isobaric supply and heat regeneration; 1-2′-3-4-1 – with isochoric heat supply without regeneration; and 1-2′-6′-3′-4′-5′-1 – with isochoric supply and heat regeneration

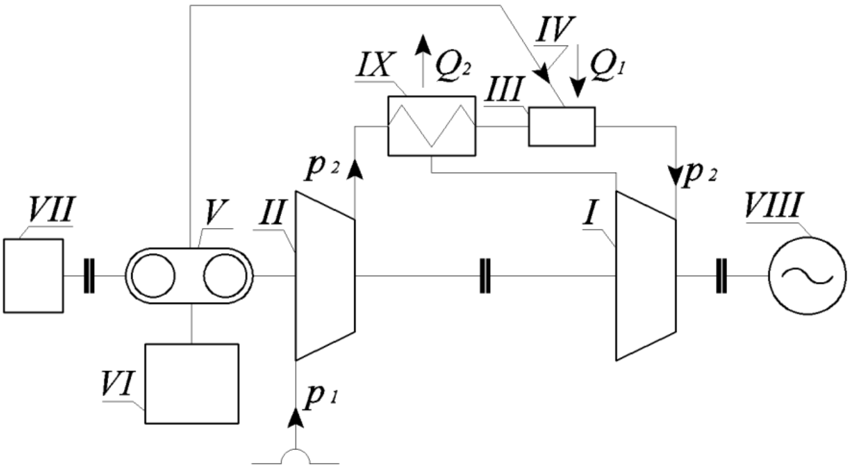

Figure: 3. Schematic diagram of a GTP with heat regeneration: I - turbine; II - compressor; III - combustion chamber; IV - nozzle; V - fuel pump; VI - fuel tank; VII - starting engine; VIII - consumer of mechanical energy (electric generator); IX - regenerative heat exchanger

Table 1. *Comparison of the characteristics of GTP cycles with isobaric and isochoric heat supply and their modifications with exhaust gas heat regeneration*

Cycle characteristics	Dimen-sion	Heat supply			
		isobaric with-out re-generation	isobaric with regeneration	isochoric without regeneration	isochoric with rege-neration
Air temperature after compression	°C	255.4		117.9	
Gas temperature at the beginning of isen-tropic expansion	°C	850			
Gas pressure at the beginning of expansion	MPa	0.7093			0.4050
Gas pressure at the end of expansion	MPa	0.1013			
Temperature of gas at the end of expansion	°C	371.0			482.67
The amount of heat supplied in the cycle	kJ / kg	597.5	504.6	525.5	315.0
The amount of heat removed in the cycle	kJ / kg	342.6	249.8	249.8	160.2
Average temperature of heat supply	°C	515.7	574.3	420.7	612.5
Average temperature of heat removing	°C	179.3	146.3	179.3	104.1
Turbine work	KJ / kg	481.3			369.1
Compressor work	KJ / kg	226.5		88.3	
Compressor to turbine work ratio	%	0.4706		0.1834	0.2392
Reducing the ratio of compressor to turbine work	Times	-	-	2.5	2.0
Specific power of gas turbine	kW	254.8		393.0	280.0
Relative increase in power density	%	-	-	54.2	9.9
The ratio of the specific power of gas tur-bine plant to the heat input	%	0.4265	0.5050	0.7480	0.8915
Thermal efficiency	-	0.4265	0.5050	0.3480	0.4915
Relative change in thermal efficiency	%	-	18.4	-18.4	15.2

Analyzing tabular data, the following conclusions can be drawn:
– the most effective thermodynamic cycle among those compared by most indicators turned out to be a cycle with an isochoric supply and heat recovery: its thermal efficiency is 15.2% higher than at the basic cycle and with a 47.3% lower amount of externally supplied heat, 9.9% more "pure" work in comparison with a gas turbine plant with isobaric heat supply without regeneration; the pressure of the gases supplied to the turbine blades decreased to 0.405 MPa against 0.7093 MPa for the base cycle;
- the thermodynamic cycle of a gas turbine plant with an isochoric heat supply without regeneration is the second most efficient among the compared cycles: despite the fact that the thermal efficiency of this cycle is 18.4% lower than that of the base cycle; the coefficient of the ratio of the unit capacity of the gas turbine plant to the heat supplied in the cycle is 0.7480 (versus 0.4265 for the basic one); the ratio of compressor to turbine work is 2.5 times less than in the basic cycle; the specific capacity of the gas turbine plant increased by 54.2% with a reduced amount of heat supplied in the "isochoric" cycle by 12.1%.

The data on the efficiency of the GTP with isochoric heat supply and regeneration given in the table were obtained at the degree of regeneration $\sigma = 0.803$, which in absolute terms corresponds to underrecovery (the temperature difference between gases and air at the outlet from the regenerative heat exchanger) 71.6 ° C. At the same time, in cycle with isobaric heat supply and regeneration at a degree of regeneration $\sigma = 0.8$, the underrecovery is 23.1 °C. Therefore, in the isochoric regeneration cycle the regeneration rate can be increased. Taking the degree of regeneration $\sigma = 0.919$, which in absolute terms corresponds to underrecovery of 30.8 ° C, we obtained a thermodynamic cycle of a GTP with a thermal efficiency of 0.5528, which is 32% higher than the efficiency of cycle with isobaric heat supply without regeneration. At the same time, naturally, the amount of supplied heat decreased to 272.9 KJ / kg.

II. SUMMARY

The performed research has shown the expediency of widespread use of GTP with isochoric heat supply without regeneration and with regeneration as power plants, especially in stationary conditions. When using isochoric heat supply instead of isobaric at the same maximum cycle temperature decreases the ratio of compressor and turbine work by 2 times. A gas turbine with an isochoric heat supply is structurally more complicated than a gas turbine with an isobarsc heat supply, but the comparative data given in the table indicate their advantages over the latter.

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Abbreviations

GTP – gas turbine plant

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