Using computer modelling when creating a heat exchanger for a complex cycle small-size gas turbine plant

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Abstract. Using the complex methodology of computer-aided design, calculation, and production, an experimental plate heat exchanger for a small-size gas turbine plant of complex cycle was created. Using a computer parametric 3D model of the base heat exchangers element (plate) allows for the design, calculation, optimization, and technological preparation of production automatically. Experimental studies of the heat exchanger for the complex cycle small-size gas turbine plant created according to the proposed methodology confirm its reliability and accuracy.

1. Introduction  
Increasing fuel efficiency is an urgent direction for improving gas turbine engines and plants in any power class. For small-size gas turbine plants (SGTP), increasing fuel efficiency is a key task. The solution to the problem of increasing the fuel efficiency of a SGTP without significant changes to the basic design is possible by installing a heat exchanger, which preheats the air entering the combustion chamber by exhaust gases [1]. The development of a heat exchanger for a complex cycle SGTP is a difficult multidisciplinary task, including design, calculation, production, and experimental research [2]. To reduce the material and time costs for the development of plate heat exchangers, it is proposed to use a comprehensive methodology, which closely links all stages of object creation.

2. Object of research  
This paper presents research on creating a plate heat exchanger for a ground-based complex-cycle SGTP, which is a compact solid-fuel power plant for generating heat and electric energy. The plant is based on the Stirling engine and is designed to generate electricity and heat with an electric power of 4 kW.  
The peculiarity of the thermodynamic scheme of the experimental SGTP is that heat is supplied to the working fluid (air) between the compressor and the turbine through the heat exchanger from an external heat source, from the solid fuel burner. This scheme assumes the residual heat of the working fluid returns to the thermodynamic cycle after passing the turbine (Fig. 1).
Figure 1. Schematic diagram of the ground-based complex cycle SGTP: K-compressor; T-turbine; HE-heat exchanger; EHS - external heat source

A key element of the complex cycle SGTP with an external heat supply is the heat exchanger. Therefore, when creating the heat exchanger, it is necessary to get the maximum possible efficiency. An analysis showed that the best heat transfer efficiency can be obtained using plates of the «Frenkel packing» type. However, it is necessary to choose the optimal configuration of the heat exchange surface, which will provide the best thermal and hydraulic characteristics.

3. Computer-aided design and calculation

The design and calculation of the heat exchanger for the complex cycle SGTP according to the proposed methodology is carried out in the following order [3].
1. Entering source data in the parametric model and setting restrictions.
2. Rebuilding the parametric 3D model.
3. Preparation of grid models of plate, air and gas.
4. Conducting a three-dimensional calculation to determine the thermal and hydraulic characteristics of the heat exchange surface.
5. Analysis of calculation results. At this stage, if necessary, the source data is corrected and then the entire cycle is repeated. When the required heat and hydraulic characteristics of the heat exchange surface are reached, the transition to the technological stage is carried out.

For computer-aided design and calculation of the heat exchanger, the initial data obtained from the parameters of the SGTP were entered in the complex methodology. The geometry of the heat exchange surface according to the recommendations of a well-known literary source [1] was chosen as the initial configuration.

Further, in automatic mode, the geometry of the heat exchange surface was optimized: obtaining the configuration with the highest regeneration degree $\eta_r$ with the lowest hydraulic losses $\Delta p$. At the same time, thermal efficiency is a priority for the ground-based SGTP. More than 200 configurations were calculated automatically, and a set of Pareto-optimal solutions was obtained. Among the best solutions, the option that provides the highest thermal efficiency was chosen:
- length of the plate $L = 200$ mm;
- width of the plate $B = 191$ mm;
- height of the plate $h = 2$ mm;
- corrugation angle $\varphi = 70^\circ$;
- the step of the corrugation $S = 6.28$ mm.

This geometry of the heat exchange surface provides a regeneration degree $\eta_r = 78\%$ and total hydraulic losses on both circuits of the $\Delta p_{sum}$ not exceeding 5%.

4. Technological preparation

After the design and calculation, the 3D model is sent to the process module, where a set of equipment is formed that is necessary for producing the heat exchanger according to the developed technological
process [4]. The technological stage of the complex methodology can be structurally represented as follows:
1. Input of initial data obtained as a result of passing the first stage of the complex methodology.
2. Building a set of forming elements for the production of the optimal geometry plate.
3. Designing the set of technological equipment for forming the input channels of the envelope.
4. Creating the equipment for positioning plates when welding plates to the envelope.
5. Forming inserts for the welding of the envelopes to the matrix.
Thus, at this stage of the complex methodology, 3D models of all the technological equipment required for production of the heat exchanger are formed.

5. Heat exchanger production and experimental study
Production of plate heat exchangers is a complex task that involves working with thin-walled and different-thickness parts. Production of the heat exchanger for the complex cycle SGTP was carried out on a low-power laser plant with numerical control (NC). The technological process of creating the heat exchanger for the complex cycle SGTP according to the proposed methodology is shown in figure 2.

![Diagram of heat exchanger production process](image)

**Figure 2.** The technological process of producing the heat exchanger for the complex cycle SGTP
The experimental heat exchanger for the complex cycle SGTP produced according to the proposed complex methodology is shown in figure 3.
To confirm the adequacy of the complex methodology, the experimental heat exchanger was tested for tightness, thermal, and hydraulic characteristics. The experimental heat exchanger in an assembly is shown in figure 4.

During experimental studies, thermal insulation was used, which allowed to reduce losses to the environment in all modes to values not exceeding 15%. Based on the results of computational and experimental studies, the thermal characteristics were constructed. The Reynolds (Re) and Nusselt (Nu) criteria were used to construct the characteristics. The obtained computational and experimental heat characteristics are shown in figure 5.
The greatest mismatch of thermal characteristics is observed at low Reynolds numbers. As the Reynolds number increases, the calculated and experimental characteristics converge with an error not exceeding 5%.

6. Conclusion
For a small-size gas turbine plant, heat regeneration is the most effective way to increase fuel efficiency. In this case, the heat exchanger has a significant influence on the parameters of the SGTP. Using the complex methodology of computer-aided design, calculation, and production of plate heat exchangers for complex cycle SGTP allows obtaining the optimal geometry of the heat exchange surface and developing technological equipment considering the requirements and restrictions set by the designer. The verification of the complex methodology of computer-aided design and calculation of plate heat exchangers showed a close convergence of the calculated and experimental characteristics.

References

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