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DEVELOPMENT OF KEY TECHNOLOGIES FOR MICRO REGENERATIVE GAS TURBINES

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Abstract

A theoretical and computational study of the heat exchanger plate type was conducted. Entering the study criterial dependence was received and a method of the plate heat exchanger parametric model was described. An evaluation method of calculation to determine the relative effectiveness and pressure loss was developed as well. The development of technology of manufacturing plates, welding envelopes of investigated heat exchanger was conducted.

1 Introduction

One of the key trends in Gas Turbine development is the machines of 30…500 kW power. The air mass flow in such Gas Turbines is 0.5…2.5 kg/s. These Gas Turbines are widely used in different technical areas.

The most important requirement is high fuel efficiency. The traditional way to optimize fuel efficiency is the cycle parameters increase. But in reality the materials and technologies available introduce very strong limitations on the cycle parameters. The problem for further fuel efficiency increase is settled with application of complicated thermodynamic cycles.

CIAM is actively working on two complicated cycles:

- The cycle with heat regeneration of waste gases;
- The cycle with external heat.

The important elements in the implementation of the program of micro regenerative gas turbines are: a rotor support, a high-speed generator and a heat exchanger.

The key element is a heat exchanger. Compact heat exchangers are found in almost every field of engineering, from energy production to transport technology [1].

Compactness is an important parameter of the heat exchanger, compact heat exchangers provides a high specific heat at their comparatively small size and weight [1, 4]. The plate heat exchangers have the highest rates of compactness and adaptability. «Frenkel's surface» at comparison of different surfaces on the specific heat transfer showed the greatest efficiency, it also has minimal weight and volume at compared surfaces directly. Comparison of different surfaces on the specific heat transfer surface showed the greatest «Frenkel's surface» efficiency, and that it also has minimal weight and volume in direct comparison of surfaces.

The main purposes of the study are:

- Development of the 3D-methods calculating of plate heat exchanger
- Development of an evaluative calculation program, allowing obtaining the most important parameters of the plate heat exchanger
- Implementation of parametric 3D-methods for designing models with complex geometric shapes, which allow reducing the time for designing.
- Development of technology for stamping and welding heat exchanger plates.

2 Calculation model

In study of CIAM, two types of the plate heat exchanger were conducted: the «Frenkel's surface» and corrugated surface (Fig. 1). Following elevation corrugations were investigated: 1.6, 2, 2.5 mm. For each elevation corrugations three angles of crossing were considered: 80 °, 100 °, and 120 °.

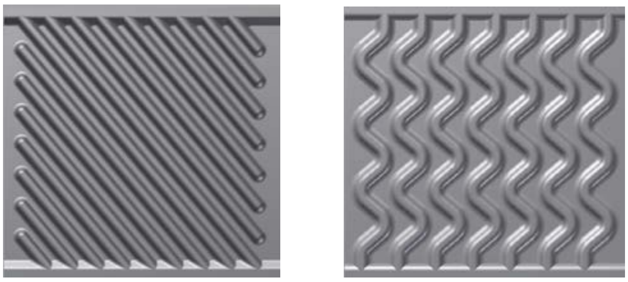

Fig.1. Variants of investigated plates

General view of the heat exchanger package of ten envelopes is presented in Figure 2. Figure 3 shows the basic dimensions of the corrugation.

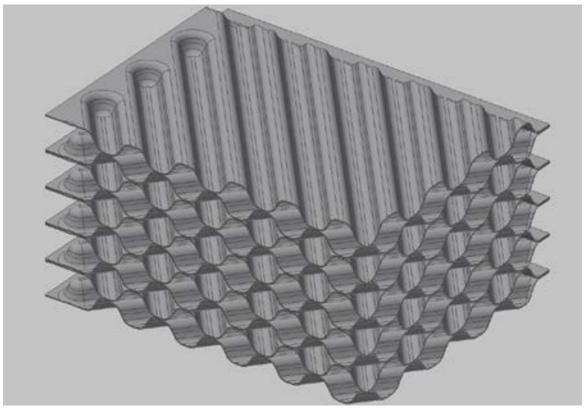

Fig.2. General view of the heat exchanger package

Main characteristics of corrugations are presented in Table 1.

Table 1

H	H_1	P	R_1	R_2	h	f	P/H
1.2	1.6	4.5	1.2	1.0	0.3	0.1	3.75
1.6	2.0	4.5	1.2	1.0	0.3	0.1	2.81
2.1	2.5	4.5	1.2	1.0	0.3	0.1	2.14

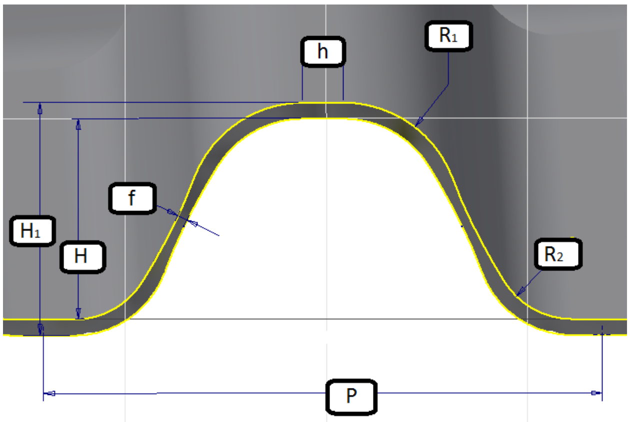

Fig. 3. The main geometrical parameters of the corrugations

The calculation model has thinning of the plate, like in real plate (f parameter), sheet thickness was 0.2 mm (Fig. 3). The Reynolds parameter is defined by the formula:

$$Re=(Vd_g\rho)/\mu \qquad (1)$$

Or

$$Re=(Vd_g\rho)/\mu=(Vd_g\rho\, F_g)/\mu\, F_g=$$

$$(d_gG)/\mu\, F_g$$

d_g – hydraulic diameter, V – velocity of the flow, ρ – density of coolant, μ – dynamic viscosity coefficient. The hydraulic diameter is defined by the formula:

$$d_g=4F_{1g}/P_i \qquad (2)$$

F_{1g} – area of one channel corrugation, P_i – the perimeter of the corrugation profile (Fig. 4). The total open area is defined by the formula:

$$F_g=F_{1g}\, Z_\kappa \qquad (3)$$

Z_κ – number of corrugations.

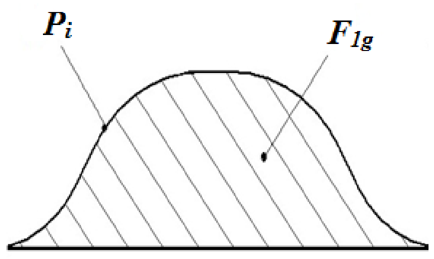

Fig. 4. Geometric parameters of the channel

P_i and F_{1g} were determined using three-dimensional program of designing, in which calculation models were created. Determination of the number Nu:

$$Nu=\alpha d_g/\lambda \qquad (3)$$

α – coefficient of heat emission of a coolant, λ – heat conductivity coefficient fluid. To determine the heat transfer coefficients of heat transfer coolants the formulas (4), (5) are used:

$$\alpha=Q/((T_{avh}- T_{avm})F_{he}) \qquad (4)$$

$$\alpha=Q/((\ T_{avm}-T_{avc})F_{he}) \qquad (5)$$

Q – quantity of the heat, which transferred through the heat exchange surface F_{he}. T_{avh}, T_{avc} and T_{avm} – average temperatures of hot and cold coolants and metal. The loss coefficient ξ was determined by formula:

$$\xi =(2\Delta P\ d_g P_{av}\ F_g^{\ 2})/(G^2 LRT_{av}) \qquad (6)$$

где $\Delta P = P_{inlet}$ - P_{outlet}.
T_{av} и P_{av} – average temperature and pressure of the coolants. L – length of the side, through which flows a coolant.

3 Methodology of design and calculation

3.1 Methodology of parametric design

In the initial stages, the designing of 3D-models of the plate and coolants for the calculation took a lot of time. Even small changes in the geometric dimensions of the plate required the 3D-models to be corrected almost entirely.

Parametric 3D-model was developed to solve this problem. This model is a set of dependencies and parameters, which are tabulated. If one of the parameters of the model is changed, everything in the model changes automatically. The creating time of 3D-model for studies decreased from 2-3 hours to 1-5 minutes in dependence on the size of the plate. This allowed making the time of a calculation studies shorter.

3.2 Verification of calculating method

For confirming that the methodology of the three-dimensional calculating can be used, the work of two types of heat exchangers was simulated, it was a tube-type heat exchanger and a plate heat exchanger, which were made in CIAM in the early 90s [3]. The first of which is the experimental section of the heat exchanger with the U-shaped tubes, developed under the leadership of A.Tihonov in CIAM. The second is an annular plate heat exchanger. It is a crossed-flow heat exchanger with «Frenkel's surface», developed under the leadership of P. Baranov in CIAM as well.

The results of numerical simulations showed convergence with experimental data within 5 ... 10%.

3.3 Methodology of calculation

The calculation was performed for an envelope consisting of two interconnected plates.
The calculation model consists of three elements: a model for metal, models for hot and cold coolant. The model presupposes that the flow of the coolant outside the plates is cold and the inner flow is hot (between the plates). Fragments of calculation model are shown in Fig.5
The dependence of periodicity is superimposed on the surface of the hot coolant and the metal, which are not interconnected, due to this the information about the processes occurring on the one surface of the calculation model elements is carried over to another surface.
A method of automatically constructing an unstructured tetrahedral mesh was used to create a simple calculation method of the plate heat exchanger and for obtaining the most plausible

qualitative assessments at a minimum expenditure of computing power and time.
SST turbulence model was used in the calculations, which is a modification of the k-omega model with the addition of wall functions.
As a result the efficiency and total pressure loss in the heat exchanger have been identified; its optimum weight and size parameters at specified temperatures and pressures on both sides were revealed. According to the obtained data desired dependencies were gained. It is showed on the Fig. 6, 7.

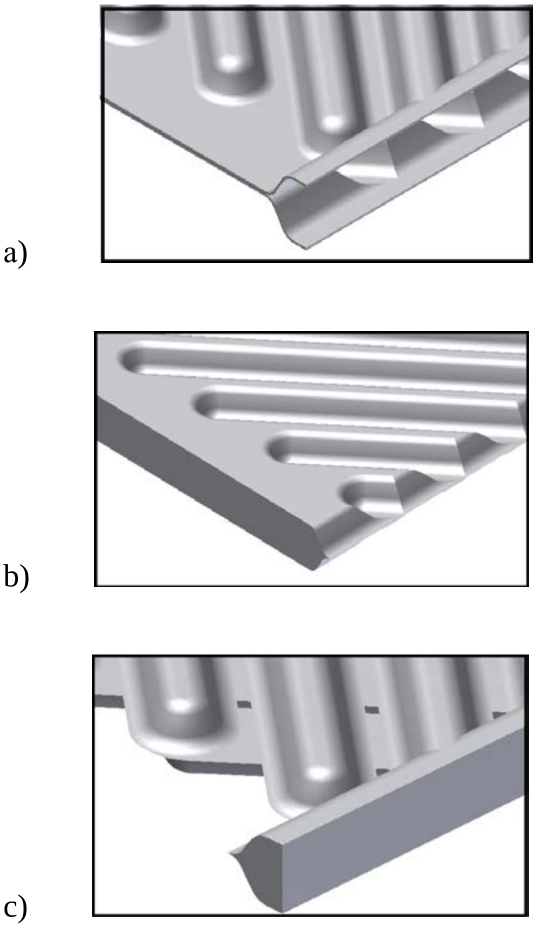

Fig. 5. Fragments of calculation model of the «Frenkel's surface»
a) Model of the metal; b) the model of the cold coolant; c) model of the hot coolant.

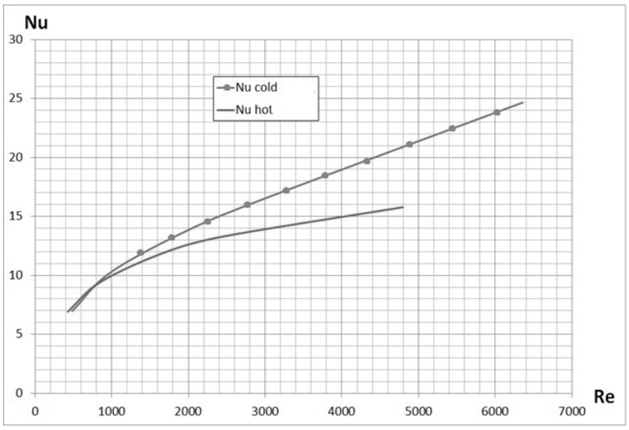

Fig. 6. Dependence of Nu (Re)

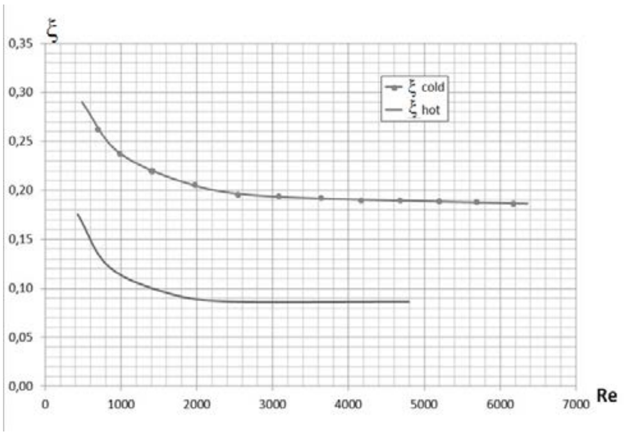

Fig. 7. Dependence of ξ (Re)

According to obtained dependencies a program evaluative analytical calculation was developed. It allows calculating pressure loss and heat exchanger efficiency for surfaces of plate heat exchanger with different geometries of corrugation.

3 Development of manufacturing technology of a heat exchanger

In parallel with the calculation research work, development of manufacturing technology of stamps, plates, welding of envelopes and packages was carried. The plates are made from a sheet with thickness of 0.2 mm and the material is CrNi45U.
At the first stage the stamping of elastic medium was used for plates manufacture. As elastic medium, polyurethane was used. However, with the use of such technology is not possible to

obtain a sufficient elevation of corrugation. In this regard, another method of manufacturing the plates was selected.
Stamping on instrumental stamps allowed obtaining a sufficient elevation of corrugation. Ready-made plate is shown on Fig. 8

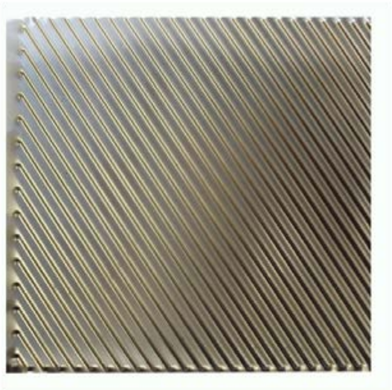

Fig. 8. The Plate, obtained by using the instrumental stamp

For the development of welding technology several options of welding were considered. Application of seam welding is the most appropriate. A seam of this kind of welding is sealed and the welding does not distort the shape of a plate.

5 Conclusion

This study has allowed developing a technology of three-dimensional calculation of plate heat exchangers. This calculation method allows obtaining a qualitative assessment of the calculated dependencies, and also allows you to see the structure of the flow path for the heat exchanger (field of temperatures, pressures and velocities).
Development of a program of evaluative calculation gives the opportunity to conduct preliminary calculations, which allows assessing the most important parameters quickly and also reduces the time for choosing the geometric dimensions of the plate.
The study confirmed the feasibility of using the parametric design methods of 3D-models of complex geometric shapes, allowing reducing the design time.
The work, which was carried out, has allowed master the technology of stamping and welding thin- sheets plates, so it allows you to create strong and sealed heat exchangers.

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