Active cooling systems for the hot zone of heat engines

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Abstract. Various types of hot zone cooling systems for liquid rocket engines are considered. The analysis of systems for external and internal cooling of the hot zone of the combustion chamber and the jet co-PLA is performed. The area of primary use of external and internal impact of components on the combustion chamber and the jet nozzle of a temporary product with a high thermal load on the material is given. Recommendations on the choice of technological methods for processing heat-protective coatings were developed, where the advantages of combined electroabrasive treatment were revealed. In this case, the possibility of finishing the transition sections of the path from areas that are difficult to access for the tool, which have coatings with ceramic granules that have been used in the latest products of aerospace technology, is shown. The mechanism of heat transfer by the cooling medium from the areas of the greatest heating, as a rule, to the flow of the liquid fuel component of the fuel is shown. Examples of implementation of modern cooling systems on typical designs of combustion chambers of modern rocket engines are considered. It is shown that the cooling efficiency will be higher the more belts of the cooling medium curtain are located along the length of the combustion chamber. At the same time, it should be taken into account that the use of an excessively large number of belts means a significant complication of the camera design, its manufacturing technology, and an increase in the cost of the product.

1. Introduction
When working with heat engines, high temperatures are used in the jet stream, which allows increasing the thrust of the rocket engine. In this case, the temperature limiter is to reduce the material strength of the engine at elevated temperatures and the duration of the period of its burning. Used hot zone cooling systems can significantly increase the resource and reliability of engines, but increase the weight of products and their cost. Liquid rocket engines use fuel components for cooling, such as liquid hydrogen, which is pumped through a complex cooling system before entering the combustion chamber. In this case, it is necessary to create paths for supplying the cooling medium, the production of which requires the use of non-traditional technological methods, which include combined processing methods.

2. Hot zone cooling systems for heat engines
Currently, the engine industry uses external and internal cooling methods. These methods are used both individually and in conjunction with other methods. Their choice depends on the type of products, their characteristics, fuel properties, capabilities and efficiency of the used technological methods for manufacturing cooling systems.
3. External cooling

External cooling of rocket engines is usually performed by one of the fuel components that flows through the jacket of the combustion chamber. Sometimes both fuel components are used for cooling; in some products, one component cools the nozzle and the other cools the engine's combustion chamber.

To increase the intensity of the province movement of the cooling component can be arranged in the opposite direction to the movement of the torch burning in the chamber during engine operation (counter current). The following requirements are applied to cooling liquids: they must be fuel components, mainly fuel; they must have the following properties: they must not boil and disintegrate under the influence of high temperature, also, they must not react with the wall materials of the system parts. When selecting media, the process limit parameters must be taken into account when the engine is running (the permissible pressure in the combustion chamber, the maximum flow rate of the coolant, and the maximum temperature of the combustion products). The criterion evaluation of these parameters is:

- the temperature of the cooled wall of the hot zone parts on the combustion side must not violate the permissible strength of the material Gorenje;
- the boiling point of the liquid cooling component at the exit from the cooling zone must be lower than the boiling point of the fuel;
- the cooling system must be part of the flow path or be Autonomous. This determines the degree of process efficiency, environmental safety, the ability to regulate the cooling system, and the choice of manufacturing processes for parts for the systems used.

4. Internal cooling

When Gorenje Gorenje is internally cooled, the engine chamber is protected from burnout by heat-shielding coatings (TP) applied from the fuel combustion side and curtains from the supplied cooling medium, which creates a layer of gas and liquid at a lower temperature than the core temperature of the combustion stream.

Figure 1 shows a layer of metal-ceramic coating applied to modern combustion chambers of rocket engines.

![Figure 1. Sample of a part with a plasma multilayer metal-ceramic nanocoating.](image)

Developed coatings (figure 1) consisting of several layers, the combination of which provides the required adhesive strength and erosion resistance of the product. For this purpose, the choice of the coating method is justified, the method of calculating the operating parameters [1] and the dynamics of the plasma torch nozzle movement is given, and the conditions for rational consumption of coating materials are shown, the size of the granules, the size of the allowance for polishing the transition areas of the coating [2]. When developing modes, for the first time, the flow characteristics of the
molten metal of the coating sublayer are taken into account for the formation of technological indicators of the two-layer nanocoating process, the outer layer of which contains mineral-ceramic granules[3].

Refractory coatings are used for thermal protection of the material wall from the combustion of fuel[4]. Since refractory coatings usually have low thermal conductivity, the temperature of the base material will be significantly lower than the temperature of the fire surface. However, in this case, low thermal conductivity is not a disadvantage (if the melting point of the coating is high enough), since the temperature change in the main material, which has a large thermal conductivity, is significantly less. The thickness of refractory plasma multilayer metal-ceramic coatings has reached 0.6 mm, which provides a resource for the hot zone of modern engines up to 20-25 starts.

Figure 2 shows the design of the nodes and the diagram of the internal curtain cooling mechanism.

![Figure 2](image_url)

**Figure 2.** Scheme and mechanism of internal curtain cooling of the combustion chamber and the rocket engine jet nozzle.

In the diagram shown in figure 2, internal cooling is performed using both fuel components: fuel 1 and oxidizer 2, which are fed through the fire disk 3 to the inner surface of the combustion chamber 4, where a liquid protective layer is formed and a curtain 5 from the burning high-temperature fuel. The effect of the curtain is enhanced by an additional supply of the fuel component through the injectors 6, which forms an additional curtain 7 on the chamber wall, flowing to the outlet through the critical section 8 of the jet nozzle 9.

5. **Mechanisms and efficiency of heat exchange when using different cooling systems**

In figure 3, the temperature change during external cooling of the hot zone of the engine is shown.

![Figure 3](image_url)

**Figure 3.** The distribution of temperature with external cooling.
The temperature 1 (figure 3) on the wall 2 of the combustion chamber depends on the pressure 3 and the temperature of the fuel components in the combustion chamber, which determines the value of the heat flow 4 acting on it. The flow path 5 of the cooling system is located on the outside of the combustion chamber. It is made in the form of longitudinal channels formed by a corrugated insert of the type shown in figure 4, or milled from the outside of the combustion chamber [2].

![Figure 4. Corrugated insert for receiving channels during external cooling of the combustion chamber.](image)

The cooling medium 6 (figure 3) flows through the slots of the insert (figure 4) in the direction 7 opposite to the movement of the flame torch 3, which provides better cooling of the wall 2. The dynamics of temperature change (8 in figure 3) shows the efficiency of external cooling of the combustion chamber.

With internal curtain convective (the most powerful) cooling, heat exchange between the combustion products and the wall occurs only through the boundary layer (a thin layer of gas directly adjacent to the wall), so to create, for economical and reliable internal cooling, it is sufficient to saturate only the boundary layer itself with “cold” (liquid or gaseous) products.

The cooling efficiency will be higher if a number of curtain belts are placed along the length of the chamber with minimal component costs. However, the use of a large number of belts means a significant complication of the camera design, its manufacturing technology, and a rise in the price of the product.

In modern combustion chambers, one to three curtain poles are installed. In this case, the fuel consumption for internal curtain cooling is within the range of 1.5...2.5 % to 6 ... 8 % of the total component consumption through the chamber. This data corresponds to a flow rate in the range of 5 ... 6 to 20 ... 25 g / cm * s, i.e. 1 cm of the perimeter of the chamber section at the location of the curtain belt.

The flow rate through the curtain belt is determined by many factors, which include: the task assigned to the curtain cooling; the number of belts in the chamber and their location. This can affect design features when designing a product.

To enhance the protective characteristics of internal cooling with the use of protective coatings, it is necessary to reduce the resistance to the movement of the combustible medium at the junction of the profile through the critical section (section 8 in figure 3). Here is the most prospective combination electroablation treatment. [5;6]. Here, the process takes place with minimal cutting forces and tool electrode wear with local tool movement for removal of processing products. For processing, flexible connections can be used to supply energy and create working movements of the tool, which gives it access to the inside of the part with limited space and complex geometry typical of modern designs of the hot zone of rocket engines.
6. Conclusion
The considered methods of cooling the hot zone of heat engines, including by applying heat-resistant multi-layer nanocoats, allowed to create a base for testing the production processability [7], and to offer technological methods for the implementation of finishing treatment of transition areas with heat-protective coatings

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