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COMPARISON OF THE PERFORMANCE OF THE DIFFERENT TYPES OF STIRLING ENGINES IN POWER GENERATION SYSTEMS

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The target of the study is to compare the output power and thermal efficiency of the three main types of Stirling engines (α, β, γ) under the same limiting temperatures (27–530 degrees Celsius) and geometric parameters.

Stirling engines, as external combustion heat engines, are becoming increasingly widespread in autonomous energy supply systems, in particular due to their ability to operate on low-potential or excess heat. A promising direction of their application is integration into fuel boilers, solar concentrators, heat exchangers, and other installations where stable sources [1] of thermal energy are present. This allows not only to provide thermal supply, but also to receive electrical energy during periods of limited generation from photovoltaic modules. Modern studies demonstrate that under appropriate conditions, it is possible to achieve a ratio of 6:1 between thermal and electrical power, i.e., to generate 1 kW of electricity for every 6 kW of thermal. Of particular interest is the use of Stirling engines as a driving force for electric generators in domestic boilers and compact boiler systems. In this context, the main challenges remain the optimization of dimensions and the design stability of the efficiency coefficient, since operation in limited volumes requires high power density, minimization of losses, and stable operation under variable thermal conditions.

All models in the study did not contain a regenerator, but took into account the influence of internal thermal radiation and the temperature dependence of the properties of air as a working medium. Numerical modeling was carried out using CFD analysis in order to build realistic profiles of temperature and pressure distribution in the working volumes. It was confirmed that design features have a critical impact on the engine performance. In particular, the α-type in the basic configuration connected by a round tube showed the lowest results - 0.908 W of power at an efficiency of 1.8% [2]. While the γ-type, which has a remote cooling chamber, achieved an efficiency of 9.8% at a power of 9.223 W. The highest results were demonstrated by the modified α-type with an annular tube: 9.856 W and 10.5%, respectively (Table 1).

Table 1 – CFD analysis results of Stirling engine types

Type of Engine	Power, Watts	Thermal Efficiency, %
α (original)	0.908	1.8
β	8.634	7.5
γ	9.223	9.8
α (modified)	9.856	10.5

The modernization of the α-type design consists of changing the geometry of the connecting channel between the hot and cold cylinders, replacing the straight pipe with a ring (toroidal) channel. This approach optimizes the internal flows of the working fluid and improves the heat exchange conditions within the working cycle. As a result of improving the thermal scheme and hydraulic structure, the modified α-type becomes promising for micro-cogeneration systems, especially in conditions of limited temperature potentials of the heat source, such as household heat generators or biomass boilers.

Overall, the study confirms the potential of Stirling engines as efficient drives in energy-efficient power generation plants. Their use as electromechanical converters in local power supply systems, as well as the ability to utilize low-potential heat, provides attractive prospects for implementation in the next-generation energy sector.

Conclusions. CFD modeling has proven the feasibility of structural modernization of Stirling engines and substantiated the prospects of their application in the field of renewable and autonomous energy. The modified α-type design provides an optimal compromise between power, efficiency, and compactness, which makes it attractive for embedded energy-efficient solutions.

References

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