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Analysis of the Stirling engine to identify the impact of various design parameters on the efficiency of its operation as part of an autonomous power complex based on renewable energy sources

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Abstract. The opportunity of application of Stirling engine with non-conventional and renewable sources of energy. The advantage of such use. It has been established that the four input parameters, the only parameter which can be easily changed during operation, and which effectively affects the operation of the engine is the phase difference. Dependence of work per cycle of the phase difference, called the phase characteristic, visually illustrates mode of operation of Stirling engine. The mathematical model of the cycle of Schmidt and the analysis of operation of Stirling engine in the approach of Schmidt with the aid of numerical analysis. To conduct numerical experiments designed program feature in the language MathLab. The results of numerical experiments are illustrated by graphical charts.

Numerical analysis of cycle DS in the approach of Schmidt

The calculations showed that in the perfect work of the regenerator efficiency of the cycle coincides with the Schmidt DS or efficiency of the Carnot cycle.

Dimensionless work per cycle $A/v \cdot R \cdot T_2$ depends on four dimensionless parameters: δ , τ , k , X .

Especially noticeable influence of the phase difference δ , so that its value can be controlled by the output of a heat engine: if $0 < \delta < \pi$, $A > 0$, that is, the system operates as an engine, with $\pi < \delta < 2\pi$, $A < 0$ as a refrigerating machine. Let us call the dependence of the dimensionless work from the phase difference between the phase characteristics. The maximum value of work the value of δ , which begins high, as does the kind of phase characteristics depend on the values of the three remaining parameters. Therefore, to characterize the influence of these parameters, it is convenient to represent in the graph the family of phase curves depending on any one of the three parameters at constant values of the other two. The following graph shows the family of phase characteristics at various values of the parameter k [1-6].

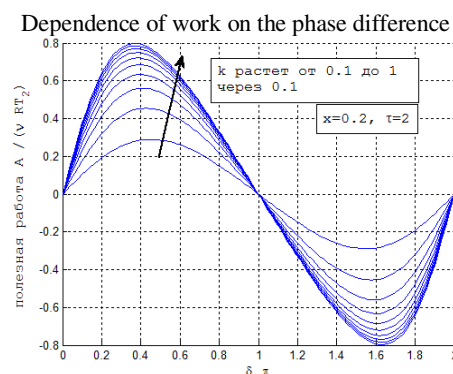


Figure 1 – Dependence of the phase characteristic from the relationship of the volume $k=V_c/V_E$ when $k \leq 1$. The arrow shows the sequence change of the curve in the collection at the specified change to the parameter k



The graph shows the influence of the phase difference δ to the value of the work per cycle. Given that the value of δ is technically easy to change in the process engine, the parameter can be used for power control of Stirling engines [7].

Many designs of Stirling engines vary the ratio of volume expansion and contraction $k = V_{c0}/V_0$.

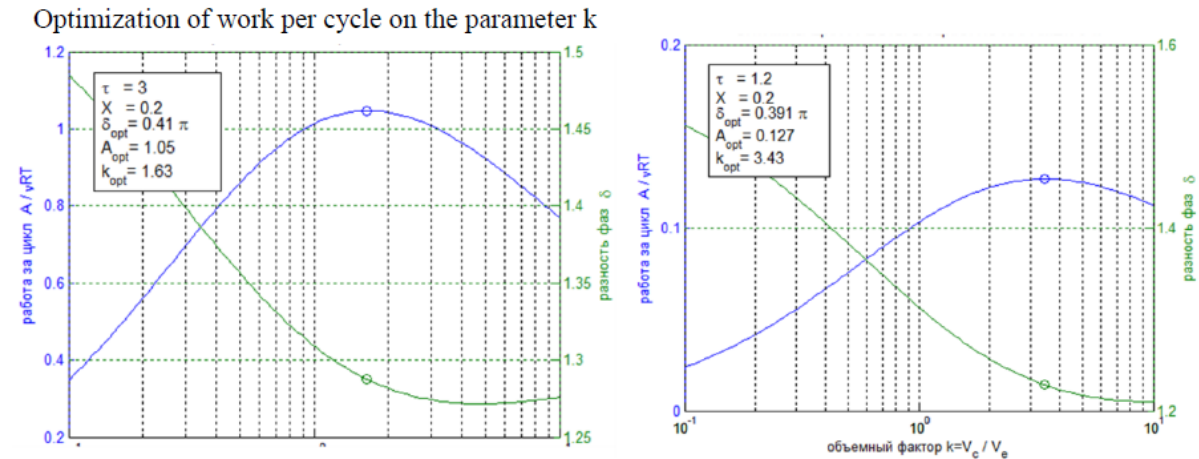


Figure 2 – Optimization of Stirling engine at the volume factor k . for different values of τ with constant value of X . Curves are shown $A_m(k)$ (in dimensionless form) and $\delta_m(k)$. Round markers indicate $A_{opt}(k_{opt})$ и $\delta_{opt}(k_{opt})$

From the previous picture you can see that the value of that $\delta = \delta_m$ maximizes value A is different for different values of k . This value, as well as the value A_{opt} , depend on two other parameters: $\tau = \frac{T_1}{T_2}$ and $X = \frac{V_D}{V_0}$.

Given that the value of δ can be adjusted in the process of operation, while, as k and X are rigidly connected with the design of the engine, and the value of τ associated with the temperature regime of work, can also be considered constant, the optimization of k can be realized as follows: by setting a specific value of τ and X , optimize A and for each value of k from a fairly wide range in the neighborhood of the optimum, identifying $A_m(k)$ and $\delta_m(k)$, and then, from the obtained values to determine the optimum k .

The following is the result of the program MATHLAB, which uses the previously described function to perform such optimization and output in a graphic window graphics $A_m(k)$, $\delta_m(k)$ values A_{opt} , δ_{opt} and the corresponding annotations [8-10].

It follows from the figure that the optimum value of k in advance should be selected based on the expected temperature range of the engine. So for $\tau=3$, which corresponds to $T_1=900$ K (627°C), $T_2=300$ K (27°C), $k_{opt}=1,63$, while for $\tau=1,2$, which corresponds to the temperature of the heater $T_1=360$ K (87°C.) at the same temperature of the refrigerator. The last case corresponds to using low-grade heat of hydrothermal reservoirs.

Each Stirling engine there is a dead volume V_D , which applies to the volume of the heater, regenerator, cooler ballast and other areas where the working fluid is not involved in the processes of compression- expansion. When designing a Stirling engine, it is important to have an idea about the impact of the proportion of dead volume to the engine. The following two drawings, made on the basis of numerical calculations explain this effect.

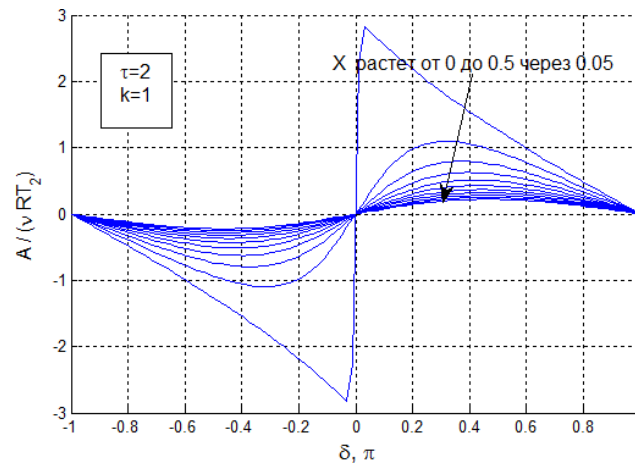


Figure 3 – Dependence of the phase characteristic of the proportion of dead volume

The figure shows that with increasing dead volume, the optimal phase shift varies almost from 0 to $\pi/2$ and at zero volume, the maximum point is unstable. With a small spontaneous decrease in δ the 2 process can go from positive to negative (the engine mode switches to the mode of refrigerating machine). From this circumstance we conclude that, although the growing proportion of the dead volume decreases maximum work, yet some of it is necessary for the stable operation of the DS.

Figure 5 shows in more detail the dependence of the optimized δ in the work and optimizes the phase difference of the proportion of dead volume X .

Dependence of the work on the fraction of the dead volume

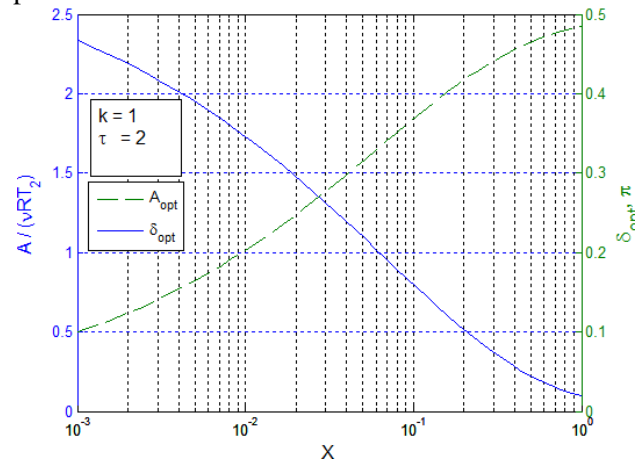


Figure 4 – dependence of the optimized dimensionless $\delta A/v \cdot R \cdot T_2$ of the proportion of dead volume X and the corresponding optimizing values δ_{opt}

From figure 4 it is seen that the increase in the share of the dead volume significantly reduces engine performance.

When using DS with various sources of thermal energy, it is important to know the effect of the temperature difference between the heater and the refrigerator on engine performance. In dimensionless form, the temperature difference relative to ambient temperature (refrigerator) is expressed by the parameter τ . To obtain the dependence from the temperature difference, an approach was used similar to that used to obtain the graphs of Fig. 4: for each τ of a certain range this value was optimized on δ and the points obtained (A_{opt}, τ) and (δ_{opt}, τ) displayed as curves on the chart. The dependence of

the efficiency of the engine from the temperature difference in the dimensionless form shown in the following image.

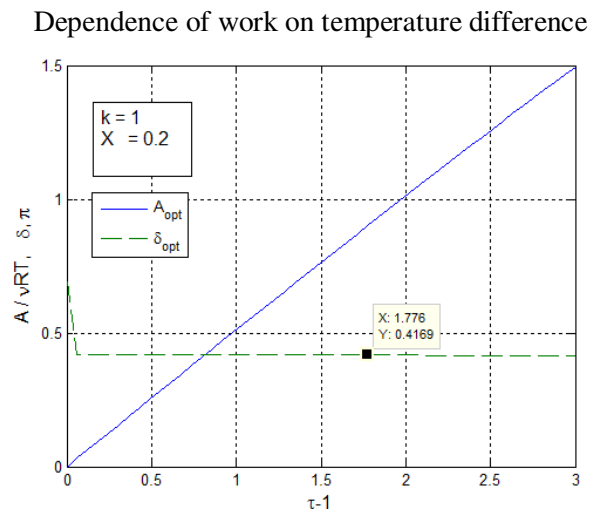


Figure 5– the dependence of the work per cycle from the temperature difference

From figure 5 it is seen that for given k and X , the work grows almost proportional to the difference of temperatures at an almost constant optimal δ .

Conclusions

Found that of the four input parameters, the only parameter that can be easily changed during operation and which effectively affects the operation of the engine, is the phase difference δ . The dependence of the cycle work from δ , called the work phase characteristics, clearly illustrates the mode of operation of the DS. Given families of phase characteristics for different modes of operation.

The paper presents the results of optimization for different temperature parameters, corresponding to high and low potential sources of heat for various values of the ratio of the volume of the compression chamber to the expansion chamber (k). The optimal value of this parameter depends on the conditions under which the calculated engine.

The results of the corresponding calculations, from which it is concluded that the decrease in the proportion of dead volume (X) leads to a significant increase in efficiency, however, too small a dead volume can lead to loss of stability of engine operation.

It is shown that the maximum in δ , the work per cycle at constant values of k , X is almost proportional to the temperature difference between the heater and the fridge.

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