Stirling engine: construction and performance analysis at low temperatures

Muzaffar Muradov[1], *Makhliyo* Tuychiyeva[1], *Rivajiddin* Muradov[2*], and *Avazbek* Axmedov[1]

[1]Namangan engineering and construction institute, Namangan, Uzbekistan
[2]Fergana polytechnic institute, Namangan, Uzbekistan

Abstract. Stirling engines, categorized as hot air engines, offer remarkable versatility by operating on a variety of fuel sources, which is a significant advantage in the context of energy diversification and sustainability. This thesis focuses on the experimental evaluation of a beta-type Stirling engine specifically designed to operate efficiently at low temperature differences. The experiments conducted demonstrated the feasibility of this engine configuration to function effectively even under lower thermal gradients, with a notable operational temperature differential of 80°C. The results revealed a direct correlation between the temperature difference and the engine's performance, as evidenced by an increase in the number of revolutions per minute (RPM) corresponding to a rise in temperature differential. This research underscores the potential applications of low-temperature-difference Stirling engines in various energy systems, propelling advancements in clean energy technologies while enhancing their practicality in real-world settings. The findings contribute to a deeper understanding of Stirling engine mechanics and their role in sustainable energy solutions.

1 Introduction

Energy reserves are decreasing day by day. Many scientists are working on unusual devices that generate energy. External combustion engines also belong to this type of engines. After Robert Stirling received a patent for an external combustion engine in 1816, these types of engines were also called Stirling engines. The advantage of Stirling engines is that they can work on any heat source. Stirling engine is also known as hot air engine. This is because it is driven by the temperature difference between the hot side and the cold side of the working piston. Stirling engines can show high efficiency even when the temperature difference is not so great. In addition, external combustion engines have the ability to work almost silently and stably.

Nowadays, it is important to use any type of energy sparingly. It is also necessary to achieve high efficiency in generating energy. Taking this into account, it is appropriate to use devices based on energy efficient, high efficiency and alternative energy sources for energy generation.

* Corresponding author: rivojiddinmurodov015@gmail.com

The ability to use different heat sources is one of the advantages of Stirling engines. Their thermodynamic properties theoretically provide the same thermal efficiency as Carnot efficiency and can be designed as small, decentralized devices[1-3].

A Stirling engine is a heat engine that operates on an external temperature difference. Due to the temperature difference, the pistons move and generate mechanical energy. Since Stirling engines are external combustion engines, we can use alternative fuels as a heat source.

Since its invention at the beginning of the 19th century, the disadvantage of the Stirling engine has been the high temperature loss of heat transfer surfaces during heat exchange with the heat source[4]. Over the years, several measures have been taken to prevent this problem, including choosing the most heat-resistant material for the heat transfer surface. In recent years, Carlsen used this strategy to develop a high-temperature differential engine for woody biomass [5]. However, this engine has not yet been commercialized and the problem of heat loss continues to hinder the practical application of Stirling engines[6].

As we know, there are basically three configurations of stirling engines. They are alpha, gamma and beta configurations. Among them, there are mainly types of stirling engines of the beta type that work at a low temperature difference (Fig. 1).

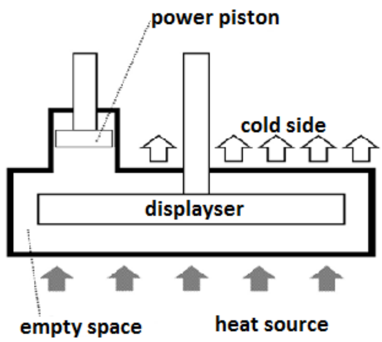

Fig. 1. Stirling engine operating at low temperature difference.

Stirling engines operating at a low temperature difference are Stirling engines that can operate in conditions where the temperature difference between the heat source and the heat sink is low. The cold side is usually atmospheric air or water[7-8].

Previous research on low-temperature-difference Stirling engines is much less than that of conventional Stirling engines. According to several reports, Stirling engines operating at low temperature differences can produce power with heat of about 100 C. In fact, low temperature is not a definite threshold temperature. Usually low temperature is taken as about 100 C. However, it is difficult to find specific ways to improve this type of stirling engine.

For example, Hirata did not call his Stirling engine a Low Temperature Difference Stirling engine, even though the Stirling engine was powered by exhaust gas from a diesel engine.[9] Conversely, Takeuchi et al called their Stirling engine a Low Temperature Difference Stirling Engine. The Stirling engine described by Takeuchi ran on 300 C oil. Therefore, a stirling engine that is not heated by direct combustion can be called a low temperature difference stirling engine. However, research by Kongtragool and Wongwises[10] described stirling engines operating at low temperature differences from other solar powered stirling engines with no heat source as well as combustion heat.

2 Materials and methods

Types of Stirling engines operating at high temperature differences are mainly started on the basis of fuel sources. For example, by burning natural gas, petrol, alcohol and even biogas. The Stirling engine of the following alpha type was also started by burning alcohol-95 (Fig. 2). When the temperature of the outer surface of the working piston of the engine exceeds 400 C, the engine is protected.

Fig. 2. Alpha type stirling engine

Among the Stirling engines operating on solar energy, the generating power of the types operating at low temperature difference is relatively low. Because Stirling engines of this type receive sunlight without concentration, their high power output is limited.

During the development process, the most suitable engine design method for low temperature difference operation was studied. The design process can be divided into basic and detailed designs. On the one hand, the detailed design process has been extensively studied in the 19th century using Schmidt cycle theory[11] and in recent years numerical simulations[12]. As in other types of stirling engines, two isothermal and two isochoric processes take place in stirlings operating at low temperature differences (Fig. 3).

To increase the efficiency of the Stirling engine, it is necessary to do the following:

1. Reduce the non-working area as much as possible
2. Using materials with high thermal conductivity for heat receivers
3. Matching the rotating wheel to the engine power
4. Use of heat sinks when using the sun as a heat source
5. Using heat spreaders on the cold side

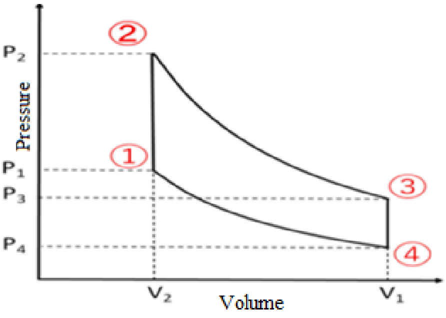

Fig. 3. An ideal Stirling cycle containing two isothermal and two isochoric processes.

To provide an initial value, Egas[13] presented and verified the formula proposed by Colin[14]. He focused on the compression ratio and proposed an empirical formula, which assumes that the appropriate compression ratio is set according to the temperature difference[15]. The formula is given as follows

$$CR_K = 1 + (T_h + T_c)/1100 \quad (1)$$

where CR_k is the compression ratio, T_h is the hot side temperature, T_c is the cold side temperature, and 1100 is the factor based on experience.

In practice, the dimensions of our device (presented in Figure 4) for testing the Stirling engine operating at a low temperature difference are as follows: the diameter of the display is 0.065 m; height 0.012 m, heat receiver piston diameter 0.07 m; height 0.03 m, power piston diameter 0.025 m; 0.01 m tall, 0.11 m long.

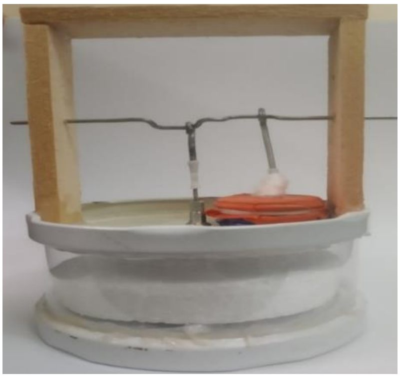

Fig. 4. A practical Stirling engine operating at a low temperature difference.

It should be taken into account that in Stirling engines there is an "untouched" area that does not work, and this area has a negative effect on performance[16].

3 Results

This device was tested at room temperature. A certain amount of heat was given to the heat-receiving piston with the help of a flame. The temperature of the cold side remained unchanged. The experimental device was operated when the temperature difference reached 800 C. As the amount of heat supplied increased, so did the speed of movement. When the temperature reached 200^0 C, the number of revolutions remained unchanged.1-jadval (fig.5)

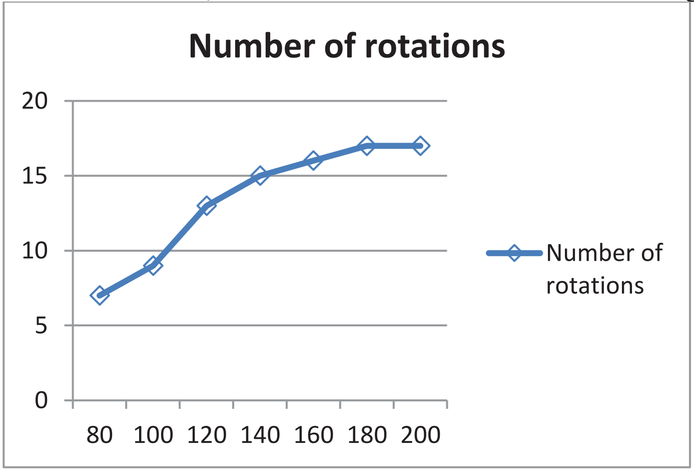

Fig. 5. Number of rotations

4 Discussion

In practical Stirling engines, frictional losses cause energy loss. An example of this is the energy losses in the walls of the piston, during movement, and in connections. Such wastes can be eliminated through experimental methods.

In addition, thermal losses reduce the efficiency of the Stirling engine. Such losses are observed in the body of the working piston when the temperature spreads to the environment and when the power piston heats up[17]. As a solution to this, insulation of the engine body and heat loss surfaces is described.

The stirling engine has advantages over various internal combustion engines in using a non-combustion heat source. Although low-temperature-difference Stirling engines can be de-braked using a low-heat source, poor power output precludes the practical use of low-temperature-difference Stirling engines[18]. The temperature of the heat source, which is considered low temperature, is not clearly defined.

The operation of stirling engines in conditions where the temperature difference between the heat-receiving piston and the cold side is small, that is, their ability to generate mechanical energy in such a limit allows them to be used even in environments that easily generate heat[19]. An example of such heat sources is heat energy from the sun.

Another thing to consider is that the material of the heat-receiving surface will undergo thermal corrosion over time if the thermal conductivity is not good. In order to avoid this, it is necessary to make the material of the receiver surface in high-temperature Stirling engines from a thicker and better heat-conducting metal.

5 Conclusions

Experiments have shown that although the mechanical energy that can be obtained is not so great, it is possible to use stirling engines working at low temperature differences. In order to reduce the engine starting temperature difference, the non-conducting area should be reduced as much as possible. Different types of heat sources can be used in this type of energy devices. It is even possible to use solar energy as a heat source [20].

Among the low temperature difference Stirling engines, the beta type is particularly convenient to use. This is because it is possible to make the surface area of the unique heat sink working piston larger. In addition, it is possible to reduce the dead volume by reducing the working area in stirlings of the betta type. This helps to increase the engine's efficiency.

References

1. Obernberger I, Carlsen H, Biedermann F. State of the art and future developments regarding small scale biomass CHP systems with a special focus on ORC and Stirling engine technologies. Int Nordic Bioenergy Conf 2003.
2. Sripakagorn A, Srikam C. Design and performance of a moderate temperature difference Stirling engine. Renew Energy 2011.
3. Murodov, Muzaffar Xabibullayevich. Educational Research in Universal Sciences **2.13** (2023): 467-470.
4. Martinez S, Michaux G, Salagnac P, Bouvier JL. Micro-combined heat and power systems (micro-CHP) based on renewable energy sources. 2017.
5. Carlsen H. Field test of 40 kW Stirling engine for wood chips. In: 8th ISECO73; 1997.

6. Kalina J, Swierzewski M, Szega M. Simulation based performance evaluation of biomass fired cogeneration plant with ORC. Energy Procedia 2017.
7. Schmidt G. The theory of Lehmann's calorimetric machine. Z Des Vereines Dtsch Ingenieure 1871.
8. Nabijon o‘g, Doktorant Murodov Rivojiddin. " PERFORMANCE ANALYSIS OF A PLAT-SOLAR-STIRLING ENGINE" Proceedings of International Conference on Modern Science and Scientific Studies. Vol. **2**. No. 10. 2023.
9. Finkelstein T. Optimization of phase angle and volume ratio for Stirling engines. (SAE Tech Paper 1960)
10. Kirkley DW. Determination of the optimum configuration for a Stirling engine. J Mech Eng Sci 1962.
11. Walker G. An optimization of the principal design parameters of Stirling cycle machines. J Mech Eng Sci 1962.
12. Caetano BC, Lara IF, Borges MU, Sandoval OR, Valle RM. A novel methodology on beta-type Stirling engine simulation using CFD. 2019.
13. Senft JR. Optimum Stirling engine geometry. Int J Energy Res 2002.
14. Hoegel B, Pons D, Gschwendtner M, Tucker A, Sellier M. Thermodynamic peculiarities of alpha-type Stirling engines for low-temperature difference power generation: optimisation of operating parameters and heat exchangers using a third-order model. Proc Inst Mech Eng C: J Mech Eng Sci 2014.
15. Walker G. Stirling engines. (Oxford: Clarendon Press, 1980)
16. Murodov M.X., Murodov R.N., Axmedov A.B. PROSPECTS FOR THE USE OF HEAT TRANSFER FLUIDS IN SOLAR-STIRLING ENERGY SYSTEMS // Economy and society. **108**, 5-2 2023.
17. Kongtragool B, Wongwises S. Thermodynamic analysis of a Stirling engine including dead volumes of hot space, cold space and regenerator. (Renew Energy 2006)
18. Kongtragool B, Wongwises S. A review of solar powered Stirling engine and low-temperature differential stirling engines. Renew Sustain Energy Rev **7**, 131–54 2003
19. Organ AJ. The regenerator and the stirling engine. (London: MEP, 1997)
20. Senft JR. Ringbom stirling engine. (New York: Oxford University Press, 1993)