Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2019, 6(12):224-229**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Thermodynamic Cycle Work in Heat Engines

İbrahim YAPICI*

*BitlisEren University of Technical Sciences Vocational School, Bitlis, Turkey
iyapici@beu.edu.tr

Abstract Heat engines are produced according to cycle types as Carnot cycle, Ericsson cycle and Stirling cycle. Each heat engine can be advantageous at several points. However, heat engines with different cycle types should be analyzed where they are disadvantageous. In this study, heat engines are analyzed according to cycle types and various evaluations are made. In addition, mathematical models of these cycles were evaluated. Accordingly, disadvantageous and advantageous situations are suggested according to cycle types.

Keywords Thermodynamic cycle, heat engines, stirling

1. Introduction

Heat engines are also known as Stirling engine. Stirling engines are theoretically the most efficient motors. With their silent and vibration-free operation, they can be used without the need for a special fuel or energy source, with the power values produced and simple designs, these engines are also used in solar energy systems today.

Advantages of Stirling engines:

- All kinds of heat sources are used in Stirling engines.
- Few moving parts. Therefore, the production cost is low.
- Easy to install and maintain compared to other engines.
- They can be manufactured as very small or very large.
- Noiseless operation.
- Stirling engine life is long.

Since combustion products do not form, they do not cause environmental pollution.

Stirling engine drawbacks;

- It takes time for the motor to decelerate and accelerate. Piston speed control is difficult.
- Since the end zone of the cylinder is continuously exposed to high temperature, high temperature resistant, high cost materials are used to prevent thermal stresses in this zone. Excessive dead volumes reduce engine efficiency.
- Since the motor is closed system, the working fluid is constantly in the cylinder.
- The sealing problem should be solved. If the problem is not solved, gas leaks occur and engine efficiency decreases.

The effect of system properties such as heat transfer coefficient of the piston material, wall thickness of the cylinder and heat transfer area and the transfer of the heat required for the operation of the engine to the working fluid in the cylinder takes time. Therefore, the first movement of the motor occurs slowly. They accelerate over time [1-6].

2. The Evolution of Heat Motors in the Literature

The solar-powered Stirling engines were first manufactured in 1872 by John Ericson. When the motor is powered by solar energy, solar collectors or convex lenses focusing the sun's rays are used. In this way, a direct heat effect is generated on the working material. Stirling motors operate according to the principle of external heat dissipation. The movement mechanism consists of heater, regenerator, cooler, power piston, piston and engine block. Regardless of the type, the heater, regenerator and cooler are essential parts of Stirling engines. The action of the movement mechanism is to move the piston and displacer in a timely manner with each other and to perform the thermodynamic cycle. In Stirling engines the sun is collected on a receiver. The radiation from the sun is converted to heat by means of the receiver focuser, and heat is transferred to the fluid [1-6].

3. Thermodynamic Rules in Heat Engines

Power generating machines generally operate according to the logic of thermodynamic cycle. Power cycles are examined during the thermodynamic process and the result is reached. During the evaluation process, conditions such as time to reach equilibrium and friction level of the system are taken into consideration. In the numerical calculation of thermodynamic cycles, some assumptions are made, such as reversible state change. Reversible state changes occur in one direction, while there are no change in the opposite direction. In practice, there is no reversible change, because there are losses in the retroactivity of any transaction. In order to simplify the cycle analysis, the process is assumed to be reversible.

3.1. Carnot Cycle

It is easy to transform work into other forms of energy. However, special arrangements are required to convert thermal energy to work. Stirling engines are machines that convert different forms of energy to work. The operation of these machines is expressed in thermal efficiency. In view of a Stirling motor operating between certain lower and upper threshold temperatures, the difference between the temperature of the working fluid and the source temperature during any thermal transfer cannot exceed the differential dT, so that the Stirling motor cycle is completely reversible. As a result of the Carnot cycle, thermal transitions work according to this rule.

In 1824, the French engineer Sadi Carnot found that the Carnot cycle has four state changes, two of which are constant temperature and the other two are adiabatic state changes. Carnot cycle P-V and T-S diagrams are shown in Figure 1 In Figure 1, 1-2 stands for reversible constant temperature compression, 2-3 stands for reversible adiabatic compression, 3-4 stands for reversible constant temperature expansion, and 4-1 stands for reversible adiabatic expansion. Visual events in the tunnel are reaction of eyes to variable light events such as adaptation of the eyes, contrast sensitivity, acuity, uniformity, flicker, and glare. Events affecting eyesight, such as flicker, uniformity, and glare, affect the quality of the tunnel lighting [3,4, 7-9]

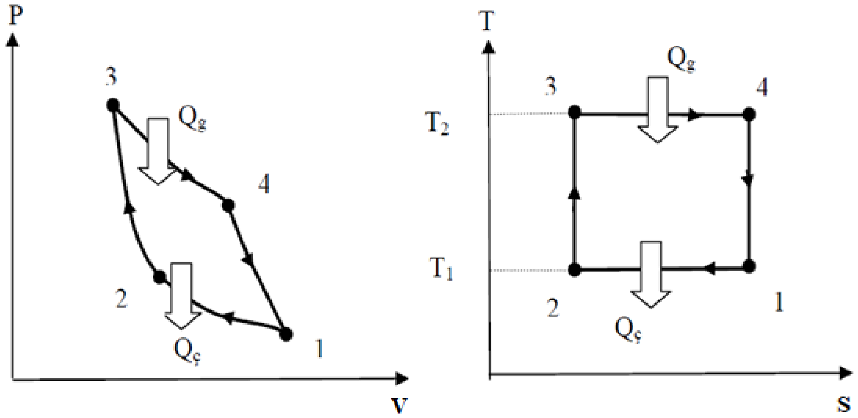

Figure 1: Carnot cycle P-V and T-S diagrams

To evaluate the operation of the ideal Carnot cycle Stirling engine, considering a piston with a closed end cylinder and a frictionless movement of the cylinder (assuming that the cylinder is insulated), the piston is at the bottom dead point at the start, ie the distance between the piston and the cylinder is greatest (at this time). Dead volume is maximum). Pressure and temperature values of the working fluid are minimum. When the piston moves towards the end of the cylinder, a volumetric compression occurs within the cylinder.

During this process, the conductivity of the cylinder end is assumed to be maximum. In this way, the process takes place at constant temperature. In order to keep the temperature constant at the other end, the heat dissipation is carried out by this welding by removing the insulation at the other end of the cylinder and approaching a large cooler to this side. At the point 2, the cold weld is withdrawn and the cylinder tip is re-insulated.2-3 state change, compression process. The cylinder head is completely insulated. When the piston continues to move towards the cylinder head, it results in a reduction in volume and an increase in both pressure and temperature. In this state change entropy remains constant.3-4 state change, reversible constant temperature expansion process. As the piston moves from the upper dead point to the lower dead point, the gas in the cylinder expands and cools. In order to keep the temperature constant at T1, the insulation at the bottom of the cylinder is removed and heat is transferred into the cylinder by approaching the hot source of infinite size, T1 temperature. When the piston reaches point 4, the cylinder head is re-insulated and hot welding is drawn. In case of 4-1 state change, compression is made to the upper dead point depending on the movement of the piston and the cycle is completed. The thermal efficiency of the cycle is given in Equation 1 [3, 9-14].

$$\eta_{th,Carnot} = 1 - \frac{T_L}{T_H} \tag{1}$$

In practice, it is not possible to implement the Carnot cycle. Because there is a need for large heat changes and long time. However, the cycle takes place in a very short time. Therefore, the Carnot cycle has no practical applicability. The Carnot cycle has become a standard for comparing real and other ideal cycles [3-9, 15-21]. Carnot cycle efficiency is a function of the temperatures given to and received from the system. Thermal efficiency increases as the temperature given to the system increases or the temperature exits from the system decreases.

3.2. Ericsson Cycle

Apart from the Carnot cycle, there are two further cycles in which the heat transfer to the cycle is at a constant temperature TH and the heat transfer from the environment at a constant temperature TL. One of these is the Ericsson and Stirling cycle. The Ericsson cycle is similar to the Stirling cycle. The heat transfer in a constant volume in the Stirling cycle takes place at constant pressure in this cycle [3-9, 15-21].

The T-S and P-V diagrams of the Ericsson cycle are shown in Figure 2. In the Ericsson cycle, Figure 1-2 shows isothermal (constant temperature) compression (heat transfer from the system to the outside environment) in the range of 2-3, regeneration at the constant pressure of 2-3 range (in-system heat transfer from the regenerator to the medium), 3-4 isothermal (constant temperature) expansion. (heat transfer from external source to the system) and range 4-1 refers to constant pressure regeneration (intra-system heat transfer from medium to regenerator)Adaptation is the ability of the eyes to adapt to variable illumination levels. In tunnel lighting, the luminance levels should be ensured through the tunnel for the driver to sufficiently see inside the tunnel from a distance to allow for safe stopping. shown in Equation 2

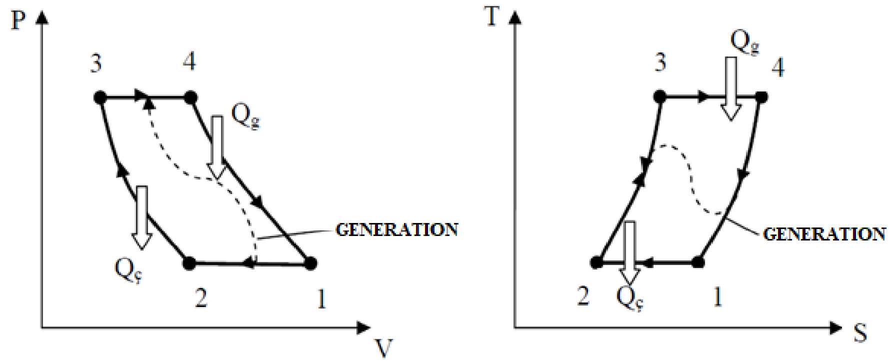

Figure 2: Ericsson cycle P-V and T-S diagrams

In the Ericsson cycle, compression and expansion take place in the compressor and turbine respectively. A counter-flow heat exchanger acts as a regenerator. The temperature difference between the hot and cold fluids at no point exceeds the amount of *dT* differential. The inlet temperature of the cold fluid is considered equal to the inlet temperature of the hot fluid. The thermal efficiency of the cycle is shown in Equation 2 [3-9, 15-21].

$$\eta_{th,Ericsson} = 1 - \frac{T_L}{T_H} \quad (2)$$

3.3. Stirling Cycle

A Stirling engine operating according to the Stirling cycle consists essentially of two pistons. One of the pistons is called the displacement piston and its task is to transport the cycle fluid between the hot and cold zone. The other piston is called the power piston and is the piston that generates power in the engine. As known from the Carnot cycle, it is known that as the difference between the temperatures of the hot and cold heat sources increases, the thermal efficiency increases. Therefore, in order to increase this temperature difference, heat transfer takes place in Stirling cycle; heat transfer within this system is called regeneration in the literature [3-9, 15-21].

The Stirling cycle is an ideal cycle for hot air engines. The P-V and T-S diagrams of the Stirling cycle, consisting of four totally reversible states, are shown in Figure 3. In the Stirling cycle shown in Figure 3.3, isothermal compression (constant temperature) between 1-2 (heat transfer from the system to the external environment), constant volume regeneration between 2-3 (in-system heat transfer from the regenerator to the fluid), isothermal between 3-4 (constant temperature) expansion (heat transfer from the external source to the system) and 4-1 range constant volume regeneration (fluid to regenerator in-system heat transfer) [3, 15-21].

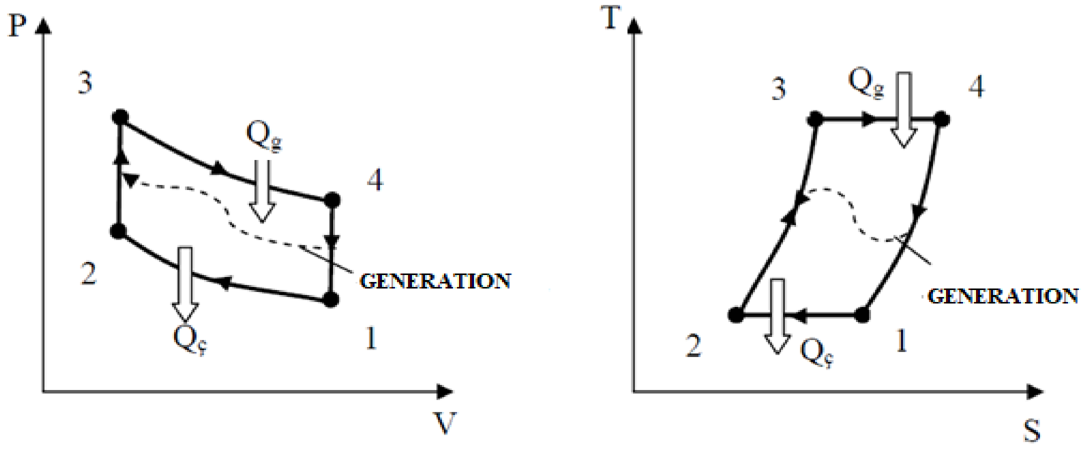

Figure 3: Stirling cycle P-V and T-S diagram [3]

How the Stirling cycle takes place is explained by a system consisting of two reciprocating pistons with a regenerator between them as shown in Figure 4. One of the volumes between the regenerator and the pistons is the expansion volume at which the highest temperature is reached, and the other is the compression volume at which the lowest temperature value is obtained.

At the beginning of the cycle, it is assumed that the piston in the expansion volume is at the upper dead point adjacent to the regenerator and the piston in the compression zone is at the lower dead point. The entire working fluid is contained in the compression volume. In this position, the pressure and temperature have the lowest value since the volume reaches its maximum value. During the compression (1-2 state change), the piston in the expansion volume does not change position while the compression piston moves to the upper dead point. The compression of the working fluid in the compression volume causes the pressure to increase. The temperature remains constant with the effect of cooling [3-9, 15-21].

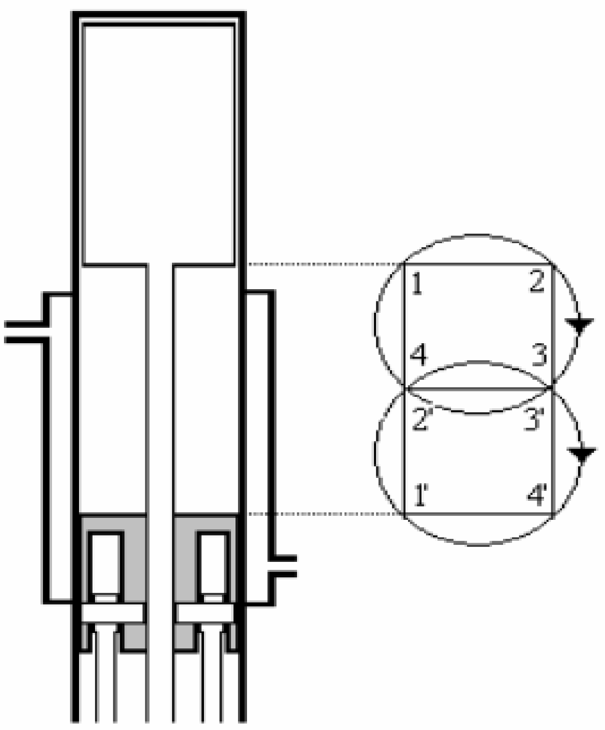

Figure 4: Stirling cycle study [22]

In a 2-3 state change, the two pistons move simultaneously with the compression piston moving towards the regenerator and the expansion piston moving away from the regenerator. In the meantime, the working fluid passes through the regenerator and is filled from the compression volume to the expansion volume. During this transition, the heat stored in the regenerator is transferred to the work fluid and the temperature value of the work fluid reaches the highest value from the lowest value. Increasing the temperature in constant volume causes the pressure to increase. In the 3-4 state change, the expansion piston moves away from the regenerator. At this time, the compression piston is adjacent to the regenerator. In the expansion process, the pressure decreases with the effect of increasing volume. With the effect of heat transferred from external sources to the system, the temperature is constant.

In the final process 4-1, the two pistons move simultaneously so that a constant volume of working fluid passes through the regenerator to fill the expansion volume to the compression volume. During the transition from the regenerator, the heat is transferred from the working fluid to the regenerator. Thus, the temperature of the working fluid is reduced and the fluid at the minimum temperature value is filled into the compression volume. During this process, the heat stored in the regenerator will be transferred to the working fluid at the 2-3 cycles of the next cycle. If the temperature limits are equal, the thermal efficiencies of these three ideal cycle methods (Carnot, Ericsson, Stirling) are equal, and this can be seen in Equation 3 [3-11, 15-21]

$$\eta_{th,Stirling} = \eta_{th,Ericsson} = \eta_{th,Carnot} = 1 - \frac{T_{Min}}{T_{Max}} \quad (3)$$

4. Results

Heat engines are produced according to cycle types as Carnot cycle, Ericsson cycle and Stirling cycle. According to the analysis, it is seen that each heat engine has an advantage over the type of cycle it has. In addition, each heat engine has been found to be advantageous at one point and disadvantageous at several points.

Therefore, special solutions must be produced in each heat engine according to the event and situation. As a result, such a classification can be understood as superior to the Carnot cycle, Ericsson cycle or Stirling cycle.

References

[1]. Stirling Engine. 2014. https://en.wikipedia.org/wiki/Stirling engine (on-line Access on 2 Oct, 2015).
[2]. Walker, G., “Stirling Engines”, United Statesby Oxford University Press., (1980)
[3]. Hacer Akhan. Güneş enerjili sıcak hava motoru, Yüksek Lisans Tezi, Trakya Üniversitesi, Türkiye, 2007.
[4]. Ericsson, J. (1870), ‘’Sun power; the solar engine’’, Contributions to the Centennial Exhibition, 571–577.
[5]. Cengiz M.S., Mamiş M.S., Kaynaklı M. (2017). The Temperature-Pressure-Frequency Relationship between Electrical Power Generating in Stirling Engines. Uluslararası Mühendislik Araştırma ve Geliştirme Dergisi, 9(2) 59-64.
[6]. Cengiz M.S., Mamiş M.S. (2016). Analysis of Electrical Efficiency in Stirling Engine for Temperature Increase. International Workshop on Special Topics on Polymeric Composites, İzmir
[7]. G.T. Reader and C. Hooper, Stirling engines, Cambridge University Press, London, 1983, 15-75.
[8]. Iwamoto I., Toda F., Hirata K., Takeuchi M., Yamamoto T., “Comparison of Low-and High Temperature Differential Stirling Engines”, In: Proceedings of the 8th International Stirling Engine Conference, 29–38 (1997)
[9]. Cengiz M.S., Mamiş M.S., Yurcı Y. (2018). Providing electrical power increase by stimulating temperature difference at low temperatures in stirling motors. Sigma Journal of Engineering and Natural Sciences, 36(1), 86-97.
[10]. Schmidt, G., “The theory of Lehmann_scalorimetric machine”, Zeitschrift Des Vereines Deutscher Ingenieure, 15, 1, 1872.
[11]. Bean, J. R. ve Diver, R. B. (1992), ‘’The CPG 5-kW dish-stirling development program’’, 27th Intersociety Energy Conversion Engineering Conference, 298- 302.
[12]. Kongtragool, B. ve Wongwises, S., “Thermodynamic Analysis of a Stirling Engine Including Dead Volumes of Hot Space, Cold Space and Regenerator”, Renewable Energy, 31, 3, 345–59, 2006.
[13]. Cengiz M.S., Mamiş M.S. (2015). A Review of Past-to-Present Literature for Stirling, Engines International Journal of Scientific and Technological Research, 1, 6, 10-19.
[14]. Abdalla S. ve Yacoub SH. (1987), ‘’Feasibility prediction of potable water production using waste heat from refuse incinerator hooked up at Stirling cycling machine’’, Desalination, 64(1), 491–500.
[15]. Finkelstein, T., Allan, J. O., “Air Engines”, The American Society of Mechanical Engineers, New York, (2004).
[16]. Hirata, K., et al., “Test Results of Applicative 100 W Stirling Engine”, Proceedings, 31st IECEC, vol. 2, p.1259-1264 (1996).
[17]. Sripakagorn, A., Srikam C.,“ Design and performance of a moderate temperature difference Stirling engine”, Renewable Energy, 36, 1728-1733., (2011).
[18]. Hirata, K., Iwamoto I., “Study on Design and Performance Prediction Methods for Miniaturized Stirling Engine”, Technology Conference & Exposion, SAE, p. 444-449, (1999)
[19]. Simetkosky M. (1985), ‘’Mod I Automotive Stirling Engine Mechanical Development’’, SAE Paper, No: 840462.
[20]. Kongtragool, B., Wongwises, S., 2006. Performance of Low-temperature Differential Stirling Engines. Science Direct Renewable Energy, 32 (2007), 547–566.
[21]. Hoegel B., Pons D., Gschwendtner M., Sellier M. 2012. Theoretical investigation of the performance of an Alpha Stirling engine for lowtemperature applications, ISEC 15th International Stirling Engine Conference, At Dubrovnik, January 2012
[22]. Çınar C., Topgül T., Yücesu H.S. Stırlıng Çevrimi İle Çalışan Beta Tipi Bir Motorun İmali Ve Performans Testleri J. Fac. Eng. Arch. Gazi Univ. 22, 2, 411-415, 2007.