Development of Stirling Engine Based Thermodynamics Tools

Uswatun Hasanah*, Rahmatsyah and Eva Marlina Ginting
Deparatment of Physics Edacation, Faculty of Postgraduate State University of Medan, Indonesia

*uswatunastrofis94@gmail.com

Abstract. A Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas (the working fluid) at different temperatures, such that there is a net conversion of heat energy to mechanical work. In the results of stirling engine experiments obtained that the influence of temperature on the speed of turning the wheel (Rpm) where the more heat the temperature is given, the greater the speed of turning the wheel produced. At a power crank distance of 3.6 cm, the resulting linearity value of 99% is obtained, at a power crank distance of 0.05 cm the linearity value of 98.69% is obtained while at the minimum distance the resulting linearity value of 98.51% is obtained. The effect of the distance of the power crank also affects the rotating speed of the wheels (Rpm) and the generated electrical energy.

1. Introduction

Human civilization that continues to develop presents changes in development and technological advances very rapidly. Technological developments encourage the development of renewable energy. Energy is the ability to do work[1]. Energy is the biggest primary need for humanity throughout the world, as the human population increases, the consumption of energy will increase. Energy sources come from living things or other objects that can be renewed or not renewed. One of the biggest energy sources that humans use is fossil energy. The used of fossil energy which continuously results in the supply will be exhausted, this will cause an energy crisis that will inevitably occur in modern times. The method used to reduce the use of fossil energy is to develop a technology that is efficient in its use. Development of technology that utilizes renewable energy as the main energy source.

Thermodynamics is the basis of physics that deals with energy, which specifically addresses the relationship between heat energy and work. Energy can change from one form to another, but energy cannot be created and destroyed (is eternal). This principle is called the principle of conservation or conservation of energy. The principle of thermodynamics is closely related to energy, which is related to natural phenomena that we encounter in our daily lives[2]. For example, the earth receives electromagnetic wave energy from the sun every day, and the earth energy is transformed into heat energy, wind energy, ocean waves, the growth process of various plants and many other natural processes. The process in humans is also a complex energy conversion process, from the input of chemical energy in the nan into motion energy in the form of all human physical activities, and energy that is very valuable that is the energy of our minds.
The concept of thermodynamics is a subject that is closely related to the field of science and technology[3]. Natural principles in various thermodynamic processes are engineered into various forms of mechanisms to assist humans in carrying out their needs. Machines are a very well-known example of an energy conversion machine, which converts chemical energy in fuels or other energy sources into mechanical energy in the form of motion or displacement on the surface of the earth, even in space. Factories can produce various types of goods, driven by electric energy generating machines that use the basic principles of thermodynamics [4]. One application of the principle of thermodynamics used in the development of the science of thermodynamics is the Stirling engine.

Stirling engine is a closed cycle heat engine that can convert heat energy into mechanical energy[5]. The Stirling engine offers possibility for having high efficiency engine with less exhaust emissions in comparison with the internal combustion engine. Stirling engines were huge and inefficient. However, over a period of time, a number of new Stirling engine models have been developed to improve the deficiencies [6]. The development of high performance Stirling engines has been investigated by many researchers, including the Development and fabrication of Alpha Stirling Engines which produce this type of engine having a high power to volume ratio [7]. The development of the use of SiC ceramic heaters with the performance of Stirling engines with free pistons results in achieving a high efficiency of 63% [8]. The purpose of this study is to develop an accurate practical thermodynamic model for the Stirling alpha type engine with the Ross Yoke mechanism [9]. Based on the explanation above, the researcher is interested in developing a thermodynamic teaching aid with the title Development of a Stirling Engine Based Thermodynamic Tools.

2. Theory
A Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gas (the working fluid) at different temperatures, such that there is a net conversion of heat energy to mechanical work [5]. Stirling engine provide clean, reliable, mechanical power when provided only with a temperature gradient. The idealised Stirling cycle consists of four thermodynamic processes acting on the working fluid:

\[ PV = Nrt \]  

**Figure 1.** Stirling cycle

Principle of the Stirling engine based on the laws of thermodynamics explains the whole closed cycle PV diagram, such as Fig. 1. The Stirling engine's work cycle consists of four processes, namely isothermal expansion, isothermal expansion, isochoric expansion and isochoric compression. To calculate the energy in the Stirling cycle
Where:

\[ P = \text{Pressure (Pa)} \]
\[ V = \text{Volume (m}^3\text{)} \]
\[ n = \text{molar quantity of gas (0.002276)} \]
\[ R = \text{universal gas constant (J.K}^{-1}.\text{mol)} \]
\[ T = \text{Temperature(°C)} \]

3. Methodology

3.1 Flow diagram of research methodology

![Flow chart](image.png)

**Figure 2.** Flow chart
3.2 Stirling engine development

Development of the stirling engine teaching aids is based on improvements made to the previous teaching aid. The development can be seen in Fig. 3.

Figure 3. Development of stirling engine teaching aids

In this research, a modification of the power crank finger will be used. The variations of the three tests in Figure 4

4(a) 4(b)
3.3 Tools and Materials
Used in this practicum
a. Stirling engine
b. Tachometer
c. Fuel is methylated

3.4 Practicum Procedures
a. Prepare a Stirling engine simulation tool uni
b. Fuel is added to the modified burner stove
c. The flame is lit on the stove, turn on the stopwatch, along with the temperature measurement on the displacer. Take data retrieval, including:
   (1) record the temperature periodically every 30 seconds.
   (2) record the rotational speed on the flywheel periodically every 30 seconds.
d. take engine stirling data

4. Result
The analysis is performed for each variation of the minimum power crank distance from 0 cm (minimum) to a maximum distance of 3.6 cm, which results in variations in temperature and the effect of the wheel rotation. The results of testing the stirling engine props carried out 3 times by taking data according to LKPD. Data collection procedures are taken from measurements temperature and rotary speed measurement temperature and rotary speed measurement (Rpm). The data analysis uses polynomial regression with order 2.
Regression analysis at maximum power crank distance(3.6cm)

Table 1. maximum crank distance experiment results 3.6cm

| No. | Waktu (dtk) | Suhu (°C) | Rpm |
|-----|------------|-----------|-----|
| 1.  | 0          | 73        | 0   |
| 2.  | 30         | 76        | 362 |
| 3.  | 60         | 112       | 411 |
| 4.  | 90         | 142       | 503 |
| 5.  | 120        | 179       | 579 |
| 6.  | 150        | 201       | 595 |

Table 1 Obtained by stirling engine starts to work at a temperature of 76 °C with the number of revolutions obtained 362 Rpm. While at 150 seconds temperature of 201 °C is obtained with many revolutions obtained 595 Rpm. The relationship of temperature to rotational speed in figure 5

The results of the polynomial regression equation can be used to predict changes in temperature ($\Delta T$) with a rotating speed (Rpm), which is obtained

$$Y = -0.0018x^2 + 2.5193x + 172.93$$

$R^2 = 0.9785$

The graph, 97.85% change in Rpm is seen influenced by temperature. That is, if the temperature change value is higher then the rotary value generated by the stirling engine is also faster. Meanwhile, the remaining 2.15% is influenced by other factors. The results of the study data obtained, the maximum value of $\Delta T$ was 201 °C, the minimum value was 76 °C with an average value of 142 °C and the maximum wheel rotational speed (Rpm) was 595 Rpm, the minimum value was 362 Rpm and the average value was 500 Rpm.
Regression analysis at medium power crank distances (0,05 cm)

Table 2. Medium crank distance test results (0,05 cm)

| No. | Waktu (dtk) | Suhu(°C) | Rpm |
|-----|-------------|----------|-----|
| 1   | 0           | 74       | 0   |
| 2   | 30          | 90       | 231 |
| 3   | 60          | 120      | 256 |
| 4   | 90          | 127      | 273 |
| 5   | 120         | 134      | 305 |
| 6   | 150         | 142      | 315 |

The results of table 2 data obtained that the stirling engine starts working at 90°C with a number of turns of 231 Rpm. Whereas at 150 seconds with a temperature of 142°C many revolutions worth 315 Rpm. The results of the 2nd order polynomial regression equation can be used to predict changes in temperature (ΔT) with a rotating speed (Rpm), which is obtained

\[ Y = ax^2 + b + c = 0.0338x^2 - 6.1081x + 505.75 \]

![Experiment graph II](image_url)

Figure 6. Experiment graph II

Figure 6 shows the relationship between the change in temperature (ΔT) and rotational speed (Rpm) in the medium power crank distance test (0.05 cm). In the graph, the linearity value produced is 96.72% which shows that the increase in temperature change (ΔT) value is higher, then the wheel rotation value (Rpm) will also increase. The result of research data obtained a maximum value of ΔT of 142°C, a minimum value of 90°C with an average value of 122°C. Meanwhile, the maximum value of the wheel rotational speed of 315 Rpm, the minimum value of 231 Rpm and an average value of 276 Rpm
Table 3. The results of a minimum power crank distance test

| No. | Waktu (dtk) | Suhu (°C) | Rpm |
|-----|-------------|-----------|-----|
| 1   | 0           | 74        | 0   |
| 2   | 30          | 91        | 128 |
| 3   | 60          | 116       | 164 |
| 4   | 90          | 127       | 175 |
| 5   | 120         | 130       | 203 |
| 6   | 150         | 137       | 220 |

The results of table 3, it is obtained that the stirling engine starts working at 91° C with a number of turns of 128 Rpm. Whereas at 150 seconds with a temperature of 137° C many rounds worth 220 Rpm.

Polynomial regression equation can be used to predict changes in temperature (ΔT) with a rotating speed (Rpm), where the following data are obtained:

\[
y = a \Delta T^2 + b \Delta T + c = 0.0348 \Delta T^2 - 5.9552 \Delta T + 382.62
\]

Figure 7 shows the relationship between the change in temperature (ΔT) and rotational speed (Rpm) in the minimum power crank distance test. In the graph, 95.79% change in Rpm is seen influenced by temperature, where the temperature changes the greater the rotation of the stirling engine also increases. The results of the research data obtained a maximum value of ΔT of 137° C and a minimum value of ΔT of 91° C with an average value of 121° C, for a maximum value of wheel rotational speed (Rpm) of 220 Rpm, a minimum value of Rpm obtained of 128 Rpm and an average value of in the amount of 178 Rpm.

The stirling props testing can be said to be valid or feasible because the results are in accordance with the theory and research results. Koddour and Benyouceff state that the more heat the temperature
is given, the greater the energy produced[10]. This opinion, is also supported by research Sahirul Alim [11] states the influence of temperature with the cyclone turbine rotational speed, where the higher the air temperature the greater the rotational speed that the cyclone turbine does.

Mathematically, it can be proven the relationship between temperature changes (ΔT) and rotational speed (Rpm). Where the equation of work done by gas can be written as

$$ W = P. \Delta V $$  \hspace{1cm} (2)

The rotating mass on the stirling wheel is used as a storage of power in the engine. The energy stored in the wheels is the amount of kinetic energy [12]

$$ E_k = \frac{1}{2} I \omega^2 $$ \hspace{1cm} (3)

By substituting each parameter known from equations 2 and 3, it can be proven that the effect of temperature change (ΔT) with rotational speed (Rpm) in equation 4

$$ W = E_k $$
$$ PV = \frac{1}{2} I \omega^2 $$
$$ nRT = \frac{1}{2} I \omega^2 $$
$$ T = \omega^2 $$
$$ I \sim \omega^4 $$ \hspace{1cm} (4)

From equation 4, it is concluded that the influence of temperature on the wheel rotational speed (Rpm) where the hotter the temperature given, the greater the wheel rotational speed produced.

5. Conclusion
From the experimental data obtained, shows that the longer the power crank distance and the higher the air temperature, the higher the spin generated by the stirling wheel.

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