

Stirling engine lab report

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1 Abstract

Within this report, a real stirling engine is captured through use of a Raspberry Pi and compared to theoretical efficiencies. It was found that theoretical efficiency decreases with input power, but the output power increased. Although, all of the input power produce relatively low efficiency compared with modern engines. There is also a significance placed on how the data is handled, and approximations (such as small angle) used to make the data easier to handle. Given more time, developing a program which calculates the volume to completeness would be useful as such a calculation is trivial to a computer.

2 Introduction

The stirling engine is a 4 stage cycle engine as illustrated in figure 1.

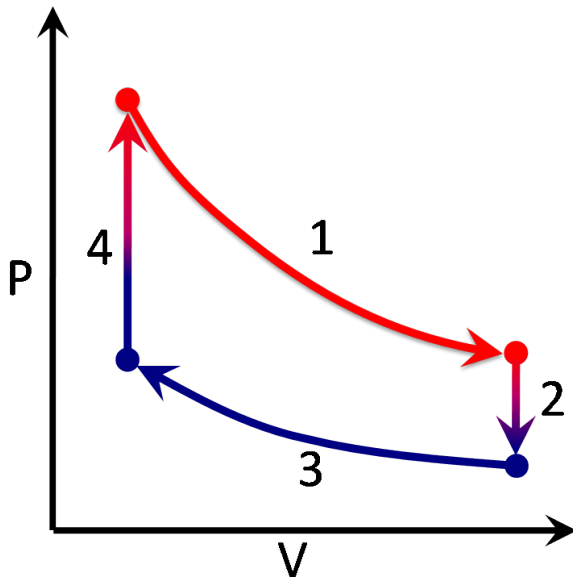


Figure 1: p-v diagram showing the ideal stirling cycle

From 1 to 2, the gas is expands due to heating from the T_{hot} source, pushes the work piston up extracting work. From 2 to 3, the displacer moves down and the hot gas begins

to cool at constant volume, resulting in a reduction of pressure. From 3 to 4, the gas cools and contracts giving up heat to the sink at T_{cold} , and both pistons move toward the centre of the cylinder. From 4 to 1, the displacer piston is moving upwards and the gas is heating, the volume of the gas remains constant but increases in pressure. The p-v diagram is very useful in calculating the cycle power as the contour integral around one cycle is the work done. $\oint_{rev} p \delta v = W_x$ - we can compare this area to our actual cycle in order to calculate the efficiency of a real device.

3 Methodology

We are able to represent the volume of gas as the sum of the volume of the large cylinder and $\pi r_{smallcyl}^2 x$ where $x = x_{total} - x'$. We have a triangular mechanism holding the small piston to the flywheel represented by the two lengths L_1 and L_2 . Thus, x' can be represented as $L_1 \cos(\pi - \phi) + L_2 \cos(\theta)$. Where θ is the angle between L_2 and the piston, and $\pi - \phi$ is the angle between L_1 and the flywheel. The maximum θ value obtainable through small angle substitution of $\cos = 1$ (sufficiently small to be accurate) is $\theta = \arcsin(\frac{L_1}{L_2})$. The ratio between L_1 and L_2 is 0.205, which would give a θ max of 0.206 (approximately $\sin \theta = \theta$). Using the approximation, at θ_{max} , the value of x is 12.6 mm. Using the true value, 13.9mm which gives a difference of 10% which is a reasonable approximation. Using the second approximation, the difference is only 0.5% at the maximum value of θ - hence this is the more useful approximation for our scenario.

For a human to calculate the energy per cycle, they can count the squares in the cycle. This is about 5 for the first heater cycle. That would give an energy/cycle value of 0.025 J. This occurred in 0.2 s, hence the power is 0.125 W. This leaves $\eta = \frac{0.125}{33} = 0.37\%$. This works as we know that $w_x = \oint_{rev} p \delta v$, so this is why this estimation works to quickly calculate the power. It is hard to make a computer "sum the squares" within a graph - so it is easier to use a numerical method using the cross product of vectors.

4 Results

Both the ideal and real cycle are much smaller than the carnot cycle, and therefore less efficient (as seen in figure 2). The carnot efficiencies are 0.33, 0.46, and 0.54 for 1, 2, and 3 heaters respectively. The ideal stirling energy output is given by $E = m \cdot (T_h - T_c) \cdot R \cdot \ln(CR)$ where CR is 1.055. The ideal stirling cycles are 0.31 J, 0.58 J and 0.81 J respectively. Ideal efficiencies are 0.9%, 0.87%, and 0.81% respectively. The real efficiencies are 0.325 %, 0.34%, and 0.35% respectively. The actual efficiency is greatly lower than the carnot efficiency or the ideal stirling efficiencies. As the power input is increased, real efficiency increases but theoretical efficiency decreases. However, running at higher input power means higher output power, and even though the efficiency may decrease there will be an improved output power.

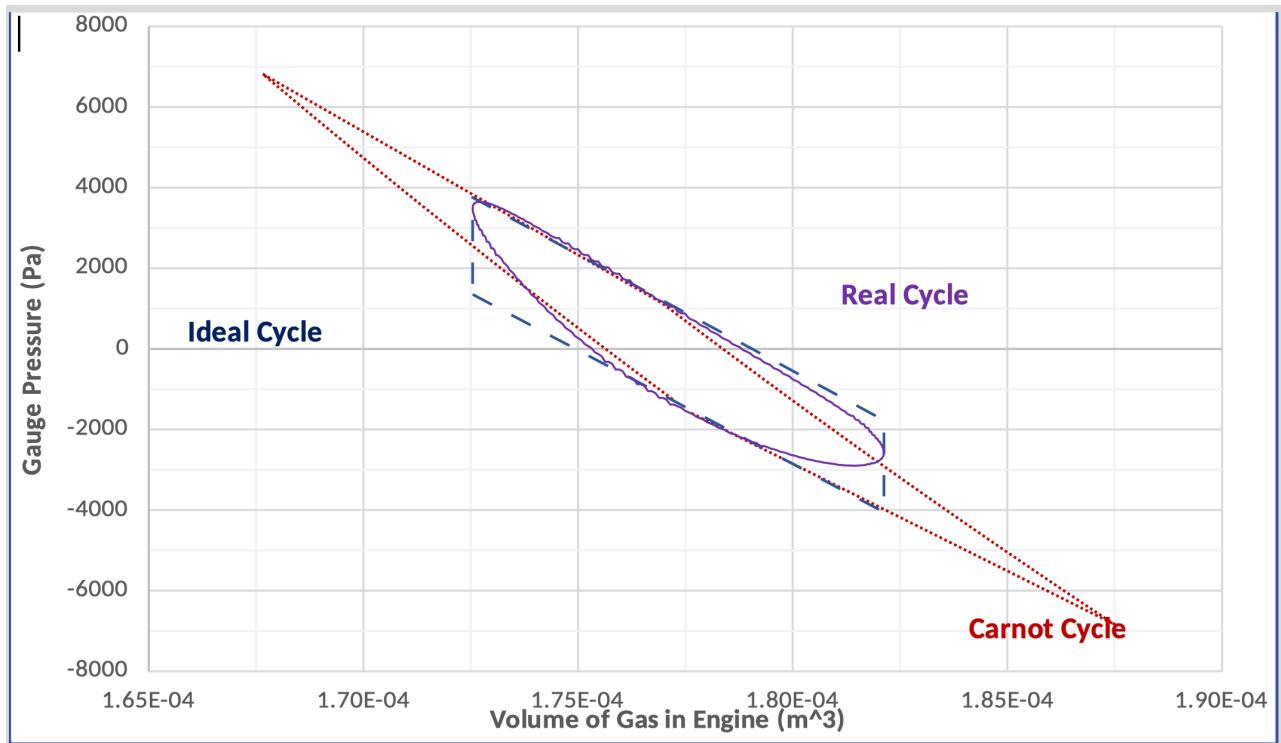


Figure 2: p-v diagram showing the stirling cycle with 1 heater

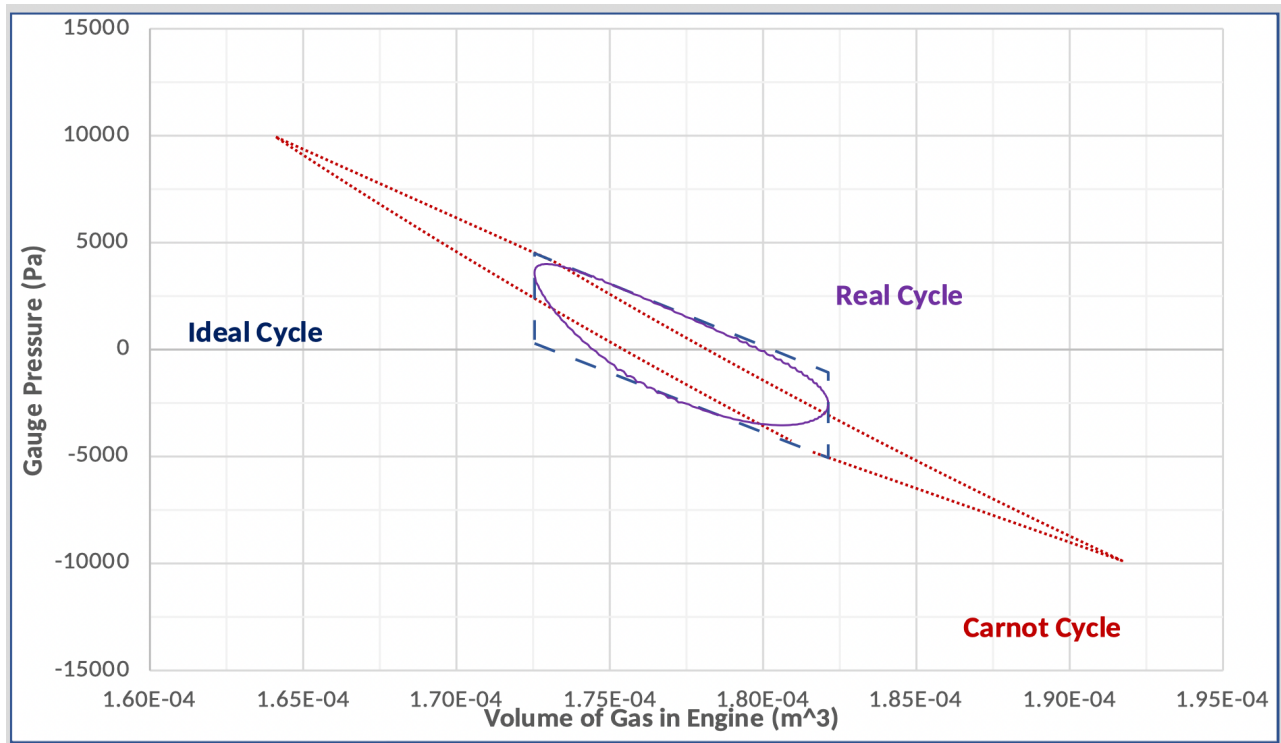


Figure 3: p-v diagram showing the stirling cycle with 2 heaters

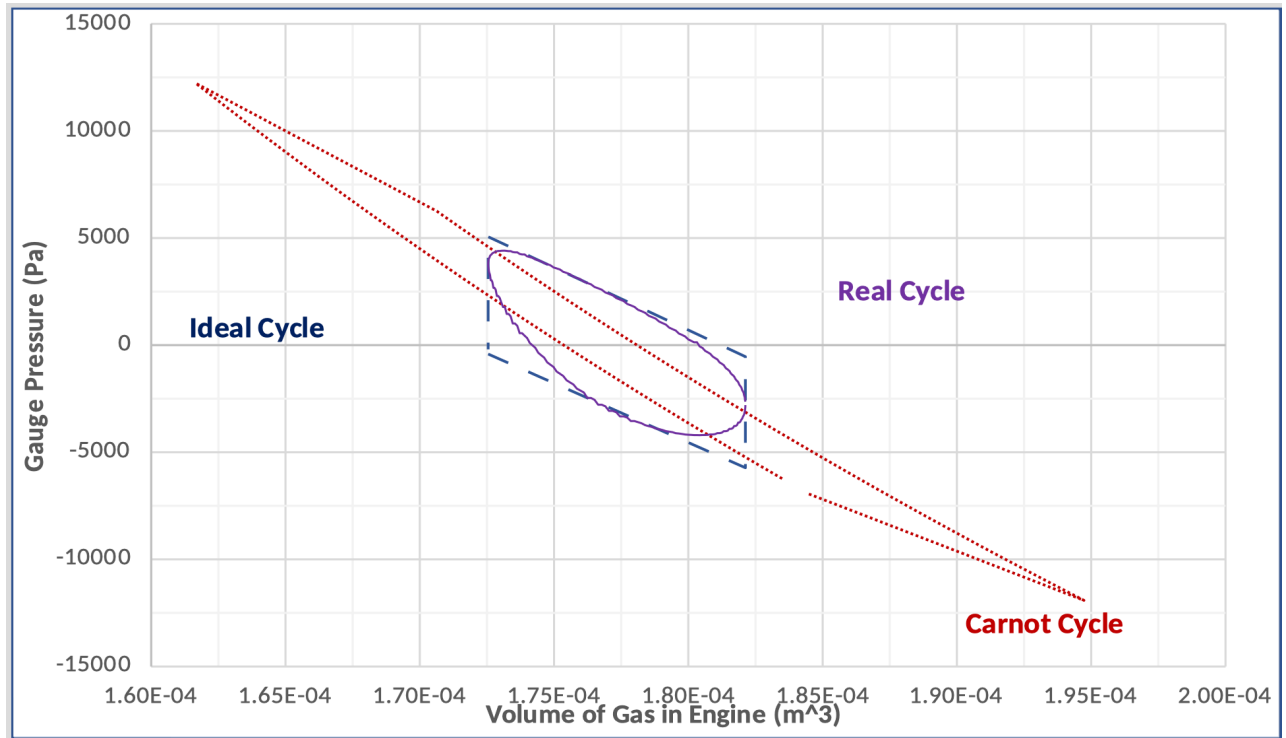


Figure 4: p-v diagram showing the stirling cycle with 3 heaters

Comparing the cycles, there is a greater range of pressures and volumes when using higher input, which you would expect as each cycle has more heat input and more work output. Greater ranges in these leads to greater variance in thermodynamic states.

5 Conclusion

By using suitable approximation and using computer logging software, it was possible to calculate the real efficiency of a stirling engine. This allows for comparison to the ideal stirling cycle and the carnot efficiency. It is also demonstrated how useful p-v diagrams can be in extracting information about a cycle. If this experiment were to be run again, a parallel T-s diagram would be great in order to see the heat transfer in and out of the system. T-s diagrams are more intuitive to see the inputs and outputs of a system as work or heat. As a sidenote, computer logging techniques are extremely important in industry in order to regulate processes within a plant. It is important to accurately know the state of your system in order to input it into a PID controller or another controller along those lines in order to feed back into the system to improve conditions and efficiency. Though, given more time - it would be easier to implement a proper calculation of the angle rather than an approximation, as for a computer running this calculation is trivial - and the accuracy sacrificed is unnecessary in this stage. The theoretical efficiency of the stirling engine reduces with higher input power, however if a certain output power is required - then the efficiency may not matter as much as the ability of the system to output the required power. Either way, this cycle is inefficient compared to modern gas power plants or modern petrol or diesel engines. It also has a relatively high power/weight ratio, which makes it unsuitable for vehicles.