# Stirling Engine

## Thermal Physics & Statistical Mechanics

UNSW AUSTRALIA

Never Stand Still | Science | School of Physics

**SKILLS GAINED**

- Operation of a thermal engine.
- Measuring torque.
- Measuring work.
- Using an oscilloscope
- Reversible thermodynamic cycles.
- Data & error analysis.
- General laboratory safety

**ASSUMED KNOWLEDGE**

- PHYS1121/1131
- PHYS1221/1231
- 1$^{st}$ year mathematics

# 1 Experimental aim

To explore the workings of a Stirling engine. To measure the torque it delivers. To measure the power output. To determine the P-V diagram of the Stirling cycle. To run the Stirling engine backwards as a refrigerator.

# 2 Background

Many different thermodynamic cycles can be used to convert heat into mechanical work. In some cases, the heating is done within the working fluid (e.g. an internal combustion engine like a diesel engine) while in others the heating is external to the working fluid (i.e. an external combustion engine like a steam engine). A Stirling engine is an external combustion engine where the working fluid is contained and reused inside the engine.

## 2.1 Theoretical background

The ideal Stirling cycle (Figure 1) comprises four steps: (I) an isothermal expansion; (II) and isochoric depressurization; (III) and isothermal compression; and (IV) and isochoric pressurisation.

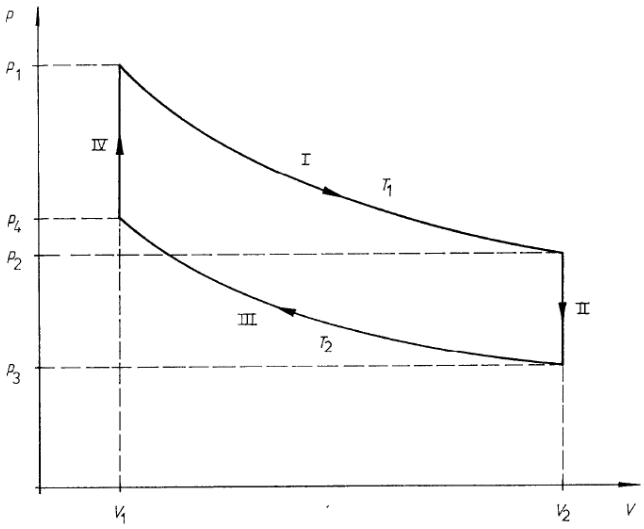



*Figure 1. Ideal Stirling cycle.*

This ideal cycle can be approximately implemented by a Stirling engine where a gas is enclosed inside at two-piston chamber (Figure 2). The hot chamber has a loose fitting piston where gas can escape around the piston. The cold chamber has a gas-tight piston, however, the bottom of the cold chamber has a gas connection allowing gas to flow between the two chambers. The two pistons are coupled to a common shaft.

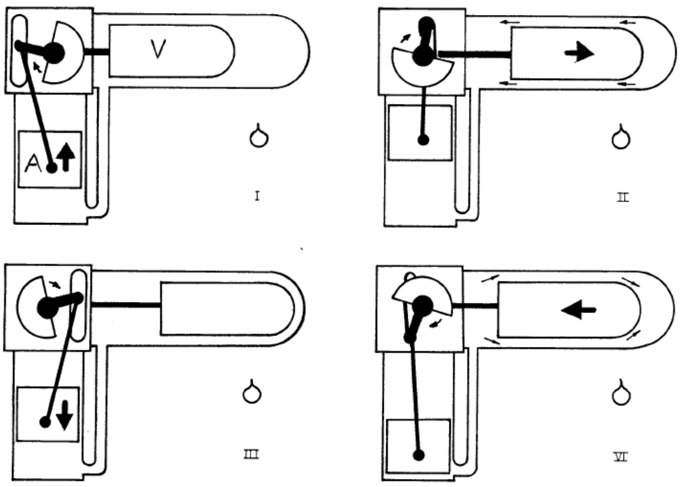



*Figure 2. Stirling engine implementing an approximate Stirling cycle. I – isothermal expansion: the heat from the spirit lamp heats the gas in the side arm tube (hot cylinder). The gas expands pushing up the cold arm piston which is gas tight, to its maximal position. II – Isochoric depressurisation: the loose hot arm piston move to its maximal position, allowing gas to flow around it. III – Isothermal compression: the tight piston in the cold arm compresses the gas. IV – Isochoric heat absorption/pressurisation: The gas volume is fixed (as the tight, cold arm piston is fully extended) and heat from the spirit lamp pressurises the gas in the side arm.*

## 2.2 Useful links:

- See Carter “Classical & Statistical Thermodynamics”.
- See Wikipedia: https://en.wikipedia.org/wiki/Stirling_engine

# 3 Prework

## 3.1 Theoretical prework

Question 1: Derive expressions for the heat flow in (or out) and the work done by each step in the Stirling cycle.

You are given the following data: For a Stirling engine operating with an ideal monatomic gas, the temperature of the upper isotherm is 400K while the lower isotherm is 300K. The maximal volume is 10 $m^3$ while the minimal volume is 2 $m^3$.

Question 2: Calculate the heat flow in each step.

Question 3: Calculate the work done by the gas in the cycle.

Question 4: Calculate the efficiency of the engine.

## 3.2 Experimental prework

Please read the Operating instructions before completing this section.

Question 5: Explain how the torque meter works.

## 3.3 Experimental plan

Now that you have done the prework, you need to come up with an experimental plan *before* you go into the lab.

### 3.3.1 Measuring the mechanical power generated by the Stirling engine.

Using the Operating instructions, the aim is to determine the performance characteristics of the Stirling engine as a function of applied mechanical torque. The torque meter applies a torque via friction that is exactly balanced by lifting a weight. So the deflection of the pointer attached to the weight give a measure of the applied mechanical load. The idea is to record the temperature difference between the cold and hot arm of the Stirling engine plus the angular velocity as a function of applied torque. Note that friction will depend on angular velocity. The torque reading will fluctuate and the adjustment of the friction (tightening of the screw holding the torque meter to the shaft) will disturb the apparatus. This should be done gently and the system should be allowed to settle after any adjustment. It is best to start with low torque values first. Do not tighten the screw so much that the Stirling engine stalls. Plot mechanical power as a function of angular velocity. Plot your results as you go.

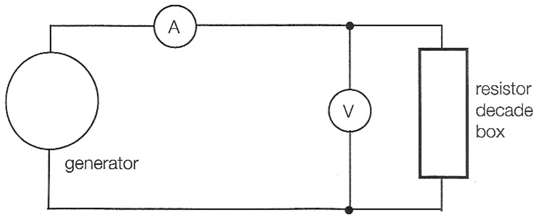
Think about the following:

- How many sets of measurements should you make?
- What are the key sources of errors in your measurements?
- How should your measurements be distributed?

### 3.3.2 Measuring the electrical power generated by the Stirling engine.

Remove the torque meter and replace it by the electrical generator as per the Operating Instructions. You have two pulleys – a small and a large pulley. Use the small pulley first and then repeat the experiment with the large pulley.

Connect the generator to a simple circuit to measure electrical power (voltage and current):




Vary the electrical load resistance starting with the highest load resistance. Record the voltage, current, angular velocity and temperature difference as a function of load resistance. Ensure that you wait until all values settle after making any adjustment or change of load. Plot your results (electrical power as a function of angular velocity) as you go.

### 3.3.3 Measuring P-V diagram for the Stirling engine cycle.

The system has an output for an oscilloscope that provides a measure of pressure and volume as two voltages that can be displayed using the X-Y function on the oscilloscope. Use the electrical load (as per 3.3.2) and record the angular velocity.

Use the oscilloscope to produce a P-V diagram. The diagram is in mV. To convert these to units of pressure and volume use the conversion factors:

V sensor output: 417 mV/mL

P sensor output: $3.75 \times 10^{-5}$ V/Pa

Measure the area of the plot to calculate the work done per cycle and hence calculate the power. If time permits, repeat this for several different loads. You can also measure P-V diagrams under mechanical load.

### 3.3.4 Using the Stirling engine as a refrigerator.

Remove the flame. Switch the electrical generator/motor to generator. Connect the 12 V supply and run the motor for a while. Record the temperature difference as a function of time until it stops changing. Feel the end of the tube.

### 3.3.5 Additional analysis.

Compare your graphs of mechanical power and electrical power as a function of angular velocity. Compare the maxima where losses are minimal and work delivered is maximal. How does the work per cycle obtained from the P-V diagram compare with measurement of electrical power output?

If you have data for P-V diagrams at different external loads, you can calculate the work per cycle as a function of angular frequency. You can then compare these values with the external work (either mechanical or electrical).