Sterling Engine

1 Objective

- Understanding how the engine works.
- Estimation of the efficiency of the Sterling Engine.

2 Prelab Questions

1. Describe how an ideal Sterling Engine should work in real life and include a schematic diagram of pistons and two chambers.
2. Draw the ideal Sterling cycle on a PV diagram and indicate the different processes.
3. On the PV diagram for each process show if work or heat exchange takes place, stating why?
4. Calculate the amount of heat and work for each process, then find the net heat and net work for the cycle.

3 Principles

- Air is trapped and is driven though a cycle where heat is provided and work is done.
- The PV diagram enables the calculation of energy obtained from the engine as work.

4 Apparatus

- Thermocouples NiCr-Ni.
- Computer with Cobra3 software.
- Connecting cables.
- Two adapters (BNC-socket /4mm plug pair).
- Scales.
- Raw ethanol.
- Stop-watch.
- pVnT metre.
- pVn sensor.
- Burner and chimney.
- Sterling Engine.
- Cobra3 basic unit.

5 Precautions

1. Wrong calibration causes a phase shift and distorts the PV diagram.
2. If the PV diagram is distorted the device needs to be recalibrated. Discuss this with your lab assistant.

6 Experimental Steps

6.1 Calibration:

1. Switch on the pVnT metre. It should read *cal*.
2. Press the T button on the pVnT metre. Now the thermocouple is calibrated to read the same temperature within a range of 1°.
3. The pVnT metre should read *ot*. Loosen the flexible tube on the left of the working piston. This step is to allow the air inside the engine to have the same pressure as the surrounding air.
4. Turn the flywheel of the engine so that the working piston is at the bottom. This is the point at which the working piston must be at its lowest point, and the engine is at its minimum volume of 32cm^3.
5. Fix the flexible tube back on again and press the V button on the pVnT metre.
6. All the monitors should be lit now, displaying $n = 0$, T_1 and T_2.
7. On the computer, open the programme Measure and click on New Measurement.
8. Choose the tab Normal Measurement and click on continue. Three windows will appear, one for Analogue 1, one for Analogue 2 and one for starting the measurement.
9. The Analogue 1 window should read 0.0V or so. The Analogue 2 window should read 2.4V or so. Record the number appearing under Analogue 2.
10. Start the measurement by clicking on Continue.
11. Turn the flywheel of the engine clockwise very slowly. This is so that the changes are considered isothermal and the ideal gas law $pV = nRT$ is applicable, where $pV = constant$ because the process is isothermal.
12. Stop the measurement after completing one full cycle of the working piston. The computer will display a graph between Analogue 1 in red and Analogue 2 in blue.
13. Observe how the Analogue 1 sensor changes between 0V and 5V, where 0V corresponds to 32cm^3 and 5V corresponds to 44cm^3.

6.1.1 Volume Modification:

(a) On the computer, modify the measurements and scale the volume axis by choosing Analysis then Channel Modification.

(b) Choose Anaglue 1 under Source Channel.

(c) Under Destination Channel, choose add new y-channel.

(d) Under Title, write Volume.

(e) For Symbol write V and give it the unit cm^3.

(f) Click on Calculate. Now the volume is calibrated so that its values range from $32cm^3$ to $44cm^3$ instead of 0V and 5V.

6.1.2 Pressure Modification:

(a) Modify the measurements and scale the pressure axis by choosing Analysis then Channel Modification.

(b) Choose Volume as your Source Channel. Notice that this channel is new, and is the one *you* created in subsection [6.1.1].

(c) Set the equation $f := 1013 \times 32/V$ under Operation. This step invokes $pV = constant$ based on the isothermal argument, explained in step [11]. *What does the function f really mean? Explain it.*

(d) Under Destination Channel, choose add new y-channel.

(e) Under Title write Pressure.

(f) For Symbol write P and give it the unit hPa. *What does hPa mean?*

(g) Click on Calculate. Now the pressure is calibrated to read values corresponding to ambient air pressure in the lab.

14. Choose Measurement then Channel Manager.

15. Set Analogue 2 on the x-axis and Pressure on the y-axis then click on OK.

16. A Convert relation to function popup will appear. In the popup, choose Average the values and click on OK.

17. The programme will now display a new graph between Analgue 2 and Pressure. Find the slope of the graph by clicking on the Slope button. The slope yields the pressure calibration factor, and it should be some hundred hPa.

18. Record the slope. You should now have two calibration factors $C1$ and $C2$, for the volume and for the pressure respectively.

19. Close the programme.

6.2 Experiment:

1. Fill the burner with raw Ethanol and weigh it.
2. Simultaneously light the burner and start recording the time using the stopwatch.
3. Place the chimney over the burner and place the burner under the Stirling engine.

4. Rotate the flywheel clockwise gently, to aid with the distribution of heat inside the engine.

5. Allow the temperature difference between the two thermocouples to read 60° before giving the flywheel a gentle push to the right.

6. After pushing the flywheel the engine should run by itself now. Allow the engine to run for about 10 minutes until it is stable.

7. Open the programme Measure and click on New Measurement.

8. Click on the Fast Measurement tab and then click on Continue.

9. Start measuring once the 10 minutes have passed and the engine is stable.

10. Record the values of n, T_1 and T_2, which are displayed on the pVnT metre.

11. A graph between Analogue 1 in red and Analogue 2 in blue. Modify the channels of the graph just like you did under subsubsections [6.1.1 and 6.1.2].

6.2.1 Volume Modification:

(a) On the computer, modify the measurements and scale the volume axis by choosing Analysis then Channel Modification.

(b) Choose Anaglue 1 under Source Channel.

(c) Set the equation $f := 32+U1\times12/5$ under Operation. *What does the function f really mean? Explain it.*

(d) Under Destination Channel, choose add new y-channel.

(e) Under Title, write Volume.

(f) For Symbol write V and give it the unit cm^3.

(g) Click on Calculate. Now the volume is calibrated and should appear as a new green curve.

6.2.2 Pressure Modification:

(a) Modify the measurements and scale the pressure axis by choosing Analysis then Channel Modification.

(b) Choose Analogue 2 as your Source Channel.

(c) Set the equation $f := 1013 + (U2 - C1) \times C2$ under Operation. *What the function f really mean? Explain it.*

(d) Under Destination Channel, choose add new y-channel.

(e) Under Title write Pressure.

(f) For Symbol write P and give it the unit hPa.

(g) Click on Calculate. Now the pressure is calibrated and should appear as a new yellow curve.

12. Click on the U1 and U2 tabs on the lower bar of the menu to hide the red and blue unmodified curves.
13. Now you must cut the graph and leave only a single cycle of the engine (trough to trough).
14. Select the + marking tool from the bar and place the cursor on one of the troughs on the yellow pressure curve. Click and drag to the left side of the graph in order to select the region you want to cut.
15. Using the scissors tool cut the region you selected to get rid of it.
16. Now select the + marking tool again and place the cursor on another trough on the yellow pressure curve. Click and drag to the right side of the graph in order to select the region you want to cut.
17. Using the scissors tool cut the region you selected to get rid of it.
18. You should now have a complete cycle (trough to trough) of the yellow pressure curve. You will also cut the green volume curve in the process, and the remaining green volume curve will be a complete cycle as well.
19. Choose Measurement then Channel Manager. Set Volume for the x-axis and set Pressure for the y-axis and click on OK.
20. In the Convert relation to function window, select Keep measurement in relation mode and click on OK. A new graph of a complete and closed cycle should appear.
21. This cycle is your first *no load* PV diagram of the unloaded engine. Click on the Show Integral button to obtain the area of the cycle in units of $\text{cm}^3 \times$ hPa. *What does no load really mean? Explain it. What does the value of the integral mean?*

7 Evaluation

1. Write down the values of n, T_1, T_2 and Δt in their correct SI units.
2. After you find the value of the integral of the PV diagram, what is the net work per cycle W_{PV} in Joules? Explain what this energy represents.
3. Extinguish the flame and weigh the burner again to find out how much of the alcohol was used Δm in the entire duration of the time Δt.

4. Find the thermal power of the engine P_h given that the Specific Thermal Power of ethanol is $h = 26.8kJ/g$.
5. Using P_h, find the supplied thermal energy W_h in one cycle.
6. How much energy was used in 5 minutes to keep the engine running?
7. Calculate the efficiency of the idealised Carnot Engine between the same temperatures. How does this compare with the energy of the Sterling Engine?

8 Postlab Questions

1. From the lab results you got, what was the energy used by the engine, the energy output of the engine in a period of five minutes? Show the calculation in details.
2. Calculate the efficiency of the Sterling Engine from the experimental data.
3. Calculate the efficiency of the Carnot Engine between the same temperatures. Compare with values obtained in Question 2 and comment on that.

9 Helpful Sites (clickable links)

- Stirling Engine with Cobra3.