Stirling Engine

Thermal Physics & Statistical Mechanics

Operating instructions

Never Stand Still | Science | School of Physics

Contents

1 Safety

The Stirling engine experiment uses a spirit lamp to heat the engine. The key safety issues are the possibility of starting a fire and burning yourself. Both the burner and the hot glass at the hot end of the Stirling engine can produce burns.

1.1 Personal safety

During the experiment you must be careful not to come into contact with the hot end of the Stirling engine or the spirit lamp. You must ensure that you do not set anything alight with the spirit lamp.

Safety Precautions!

- Check the location of the Fire Extinguisher & Fire Blanket before you start.
- Tie back loose or long hair and secure loose sleeves. Do not wear synthetic clothing.
- Never reach across a naked flame.
- The spirit lamps will be filled with ethanol and ready for you to use. Please ask your demonstrator or lab staff if the provided spirit lamps run out of fuel.
- Never leave a lit spirit lamp unattended.
- Wear safety goggles while using the stirling engine.
- Use heat-resistant gloves to pick up hot objects (the glass chimney etc).
- The Fire Extinguishers in the lab use CO_2. Their output is very cold – do not spray onto people from close range.
- The Fire Blanket should be fully extended and then wrapped around the part of the person that is alight. Gently pat the blanket to extinguish the flames

1.2 Responsible equipment use

2 Operating instructions

Figure 1. The transparent Stirling engine.

The Stirling engine is shown in Figure 1. The transparent tube on the right hand side is the hot part of the engine. The glass tube sits above the spirit lamp that is the source of heat. A plastic flywheel is central on the left of Figure 1. Below the flywheel shaft, is the gas tight piston the works on the cold arm of the Stirling engine.

The Stirling engine is powered by the spirit lamp (Figure 1).

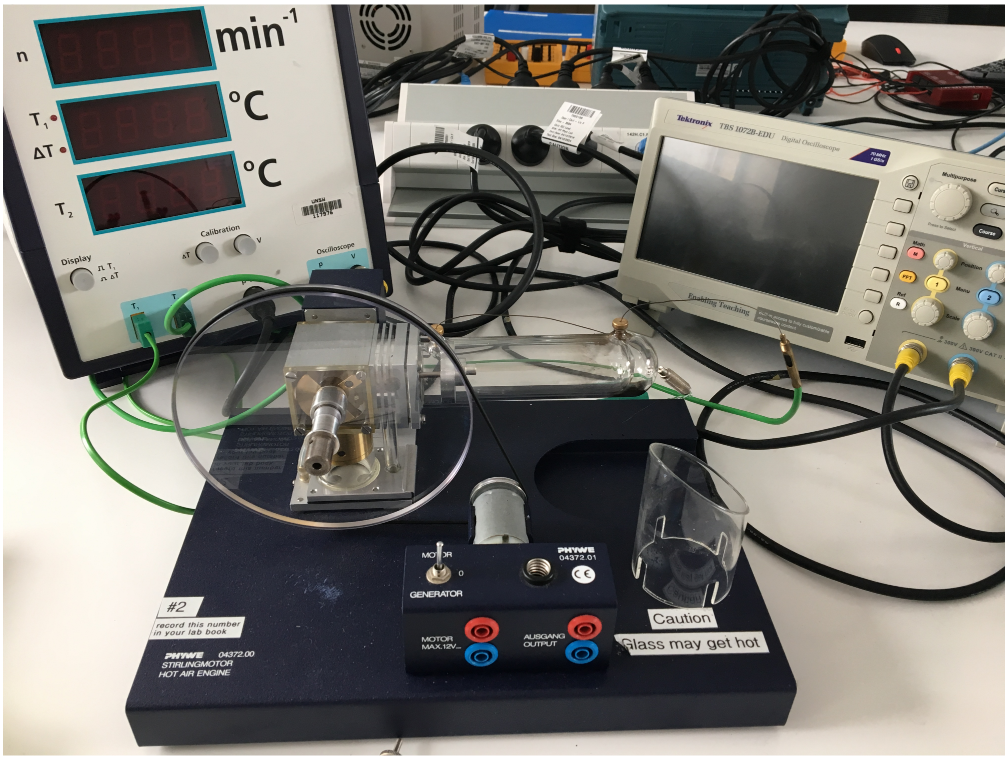

Figure 2. Stirling engine set up with an electrical generator/motor (right foreground) coupled to the flywheel via a fanbelt. The motor performance parameters are read via the control box at the rear left. An oscilloscope is coupled to the controller so as to output a P-V diagram.

The read out from the Stirling engine is via the control box (Figure 2). This reads the temperature difference between ambient and the hot arm of the engine. It also reads the rate at which the motor turns (rpm). The control box has an output for an oscilloscope that provides the read out of pressure versus volume.

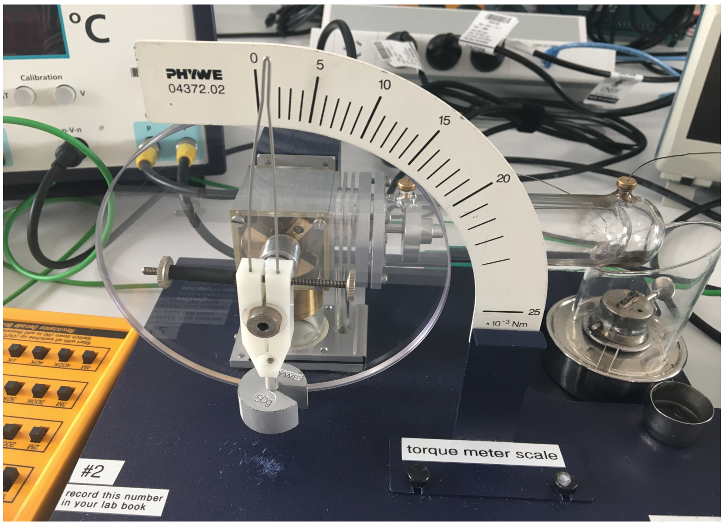

Figure 3. Torque meter. The needle and weight assembly is coupled to the Stirling engine shaft via a clamp that slides on the shaft with a certain friction. The level of friction is controlled by a screw that tightens the clamp. The scale is attached to the motor base and provides a measure of the torque.

A torque meter is provided (Figure 3). It consists of a needle and weight assembly that can be clamped onto the flywheel shaft. It couples via friction and can be adjusted via a screw so to adjust the level of friction to the shaft. Tightening the screw increases the friction. When coupled, the torque meter will lift a weight until the torque due to the weight is balanced by friction. This can be read off on a scale attached to the motor (Figure 3 right).

2.1 Equipment set-up

Figure 4. The experimental apparatus for the Stirling engine. The kit includes: resistance box (front left); a control box (rear left); an oscilloscope (rear right); two multimeters; an electric motor/generator (front right); a torque meter (front centre) and the Stirling engine (front centre).

The components available for the Stirling engine experiment are shown in Figure 4. The exact nature of some components (resistance box, oscilloscope) may differ from the picture.

2.2 Calibration.

The measuring instrument associated with the Stirling engine will need some initial calibration when first turned on. Once the instrument has performed some internal calibration it will display ‘CAL’ on the middle display.

The apparatus is stabilized at room temperature. Press the left hand Calibration ΔT button. This will set the difference ΔT= 0 between two thermocouples. The instrument will now display ‘OT’ on the upper display. (This is an abbreviation of ‘Oberer Totpunkt’, the equivalent of ‘top dead centre’ in English). Rotate the perspex flywheel until the metal piston is at its lowest point. Now press the right hand Calibration V button. The three displays should now be on, showing the angular velocity revs/min, and the actual temperatures for T_1 and T_2.

The instrument is now ready for use. The spirit lamp can be lit and placed under the end of the glass displacement cylinder using the glass chimney to concentrate the heat - careful - this chimney and the glass displacement cylinder will be get HOT during the experiment. Start the engine by a gentle clockwise spin of the perspex flywheel.

1. To apply a mechanical load and measure torque and thus mechanical work, attach the torque meter as described above (you cannot have both the torque meter and the electric motor/generator attached simultaneously).
2. To measure electrical work as a function of electrical load or to use the Sterling engine as a refrigerator, replace the torque meter by the electrical motor/generator. Couple the electrical motor to the flywheel via the belt. Build a circuit so that the electrical motor runs a current through a resistor (variable resistance decade box). Insert an ammeter and a voltmeter to measure the voltage drop across the resistor and the current flowing through it.
3. To get a P-V diagram, use the oscilloscope. Use the electrical load to get P-V diagrams at different angular velocities. Use the area of the P-V curve to calculate the work per cycle.

2.3 Using the oscilloscope

- Switch on the computer (used in the next section).
- Turn on the digital oscilloscope.
- Set the oscilloscope display to X-Y mode. This mode compares the voltage level of the two waveforms point by point. The X-Y mode displays channel 1 on the horizontal axis and channel 2 on the vertical axis. To select X-Y mode, press the “Utility” soft key (on the right panel of the oscilloscope). A menu will appear on right hand side of the oscilloscope screen. Use the adjacent soft keys to make your selections.
- Select “Display” then choose the following:
- Select “Format” and use the multipurpose knob to scroll through the available options. Push the knob to select your option. Select “XY”. A tick will indicate the option is selected.
- Select “Persist > Off” (try other settings to see what happens!)
- Select “Type > Vectors” (try other settings to see what happens!)
- Now check your scaling factors. There are two individual menus for channel 1 (coloured yellow) and channel 2 (coloured blue) on the oscilloscope. Each channel display can be controlled with two knobs: “Position” and “Scale”.
- You can change the sampling rate using the “Scale” knob under the “Horizontal” menu on the oscilloscope. We found 10 ms works well. Change the “Scale” knob to

see what happens. Use both “Type > Vectors” and “Type > Dots” mode to see the difference.

- The work performed in each cycle by the Stirling engine should equal the area enclosed by P-V diagram.
- Connect the oscilloscope to the computer using instructions in 2.4 and print out your P-V diagram. The work performed in each cycle by the Stirling engine should equal the area enclosed by P-V diagram.
- To estimate the area under the pV diagram follow the procedure below:

First cut out the image of the oscilloscope screen from your printout and weigh it on the laboratory scale. You now can calculate the weight of each square division. You can now calculate the value of S. Where will the error in S come from? One way to estimate the error in cutting the paper is to cut the square and the pV diagram on the outside of the line and weigh it; then cut the line off and weigh again. Knowing S, you can now determine the work W performed in each cycle by the Stirling engine:

$W= k_1 k_2 S$

where S is the area of the p-V diagram on the oscilloscope screen or printout in terms of the area of one square division and k_1 and k_2 are the X and Y axes conversion factors.

Conversion factors for sensors:
V sensor: output = change in voltage/change in volume = 417 mV/ml
P sensor: output = change in voltage / change in pressure = 3.75×10^{-5} V/Pa

2.4 Operating the oscilloscope via computer

On the computer desktop click on “OpenChoice Desktop” icon shown below.

Figure 5. The OpenChoice Desktop icon.

The OpenChoice Desktop will open. Click “Select Instrument” then choose the instrument name starting with “USB…” and click “OK” (see Figure 6).

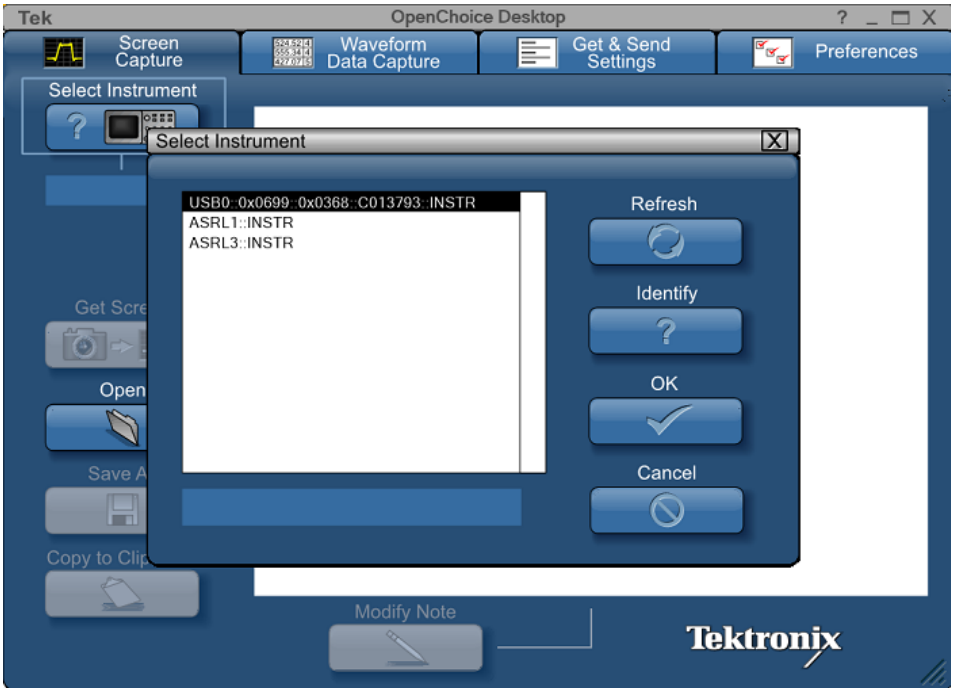

Figure 6. The OpenChoice Desktop.

To capture the display shown on the oscilloscope click "Get Screen" (Figure 7), and a Progress bar (Figure 8) will appear before the oscilloscope display is shown in the OpenChoice Desktop software.

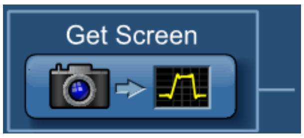

Figure 7. Get Screen button

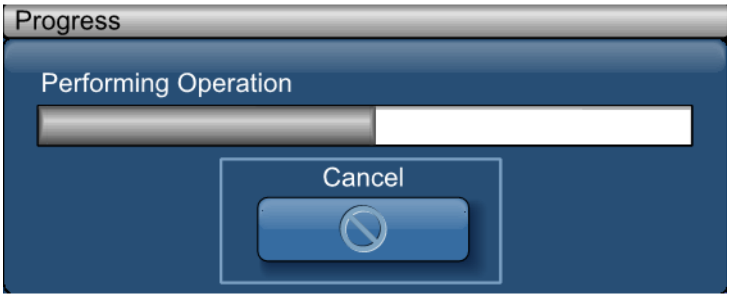

Figure 8. Progress bar which appears after you select "Get Screen".

Now you have an image of your P-V diagram.

Printing and measuring your P-V diagram.

1. Hit Print screen key
2. Paste the picture in Paint.
3. Crop the picture so it only contains the current selection of the oscilloscope screen image.
4. Right click in the selected image and choose "Invert color".
5. Now you can print the inverted image which will have a low percentage of black.

To estimate the area under the pV diagram follow the procedure below:

First cut out the image of the oscilloscope screen from your printout and weigh it on the laboratory scale. You now can calculate the weight of each square division and then the value of S. Where will the error in S come from? One way to estimate the error in cutting the paper is to cut the square and the p-V diagram on the outside of the line and weigh it; then cut the line off and weigh again. Knowing S, you can now determine the work W performed in each cycle by the Stirling engine:

$$W = k_1 k_2 S$$

where S is the area of the p-V diagram on the oscilloscope screen or printout in terms of the area of one square division and k_1 and k_2 are the X and Y axes conversion factors.

Using the conversion factors given below, calculate the work per cycle for each graph and hence calculate the power. If time permits repeat your measurements for several different loads.

Conversion factors for sensors:

V sensor: output = change in voltage/change in volume = 417 mV/ml

P sensor: output = change in voltage / change in pressure = 3.75×10^{-5} V/Pa