



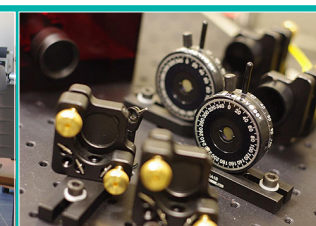
DLF

**DYDAKTYCZNE
LABORATORIUM
FIZYCZNE**

Instytut Fizyki Doświadczalnej
Wydział Matematyki, Fizyki i Informatyki
UNIwersytet Gdański

Experiment 9

Study to determine the characteristics of a Stirling engine

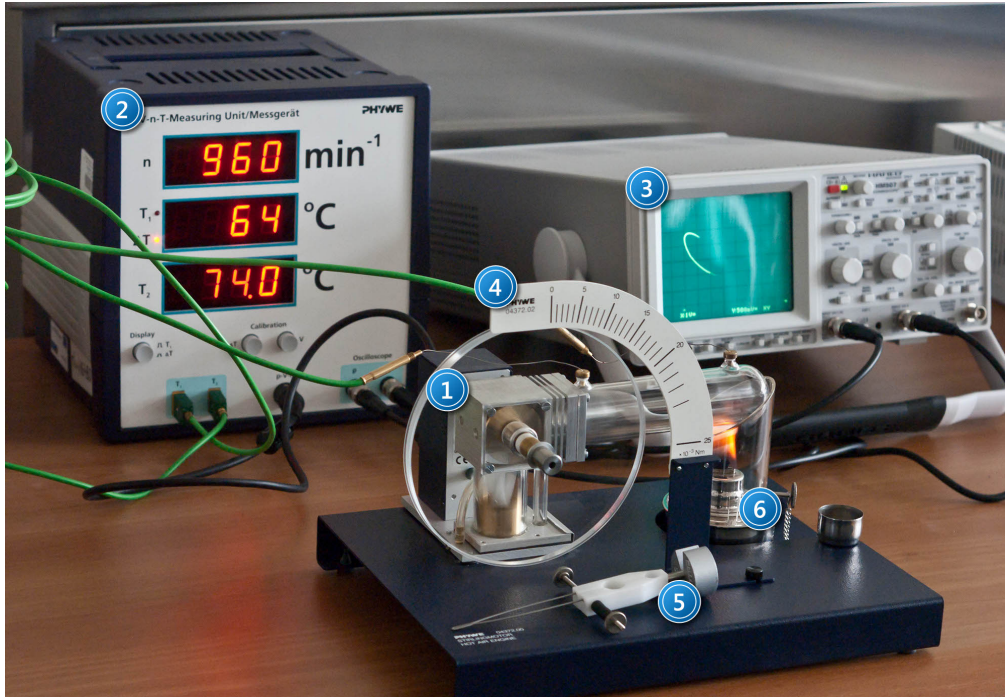


I. Background theory.

1. Uniform circular motion:
 - a) angular velocity;
 - b) linear velocity;
 - c) torque;
 - d) power in circular motion;
 - e) moment of inertia.
2. Measuring temperature and temperature scales.
3. Construction and use of thermocouples.
4. Specific heat, evaporation, liquid combustion.
5. Thermodynamic processes:
 - a) ideal gas equation of state;
 - b) isothermal processes;
 - c) isochoric processes;
 - d) isobaric processes.
6. First and second law of thermodynamics.
7. Carnot cycle:
 - a) adiabatic equation;
 - b) isothermal equation;
 - c) work, heat and internal energy;
 - d) Carnot's theorem.
8. Heat engines.
9. Stirling engines:
 - a) design and operation;
 - b) advantages and disadvantages of the Stirling engine;
 - c) use of Stirling engines.

II. Experimental tasks.

1. Refer to the measurement set-up shown in *Picture 1*.



Picture 1. Measuring system with Stirling engine: 1 – Stirling engine model; 2 – p-V-n-T meter; 3 – oscilloscope; 4 - measuring scale; 5 - torque-meter; 6 - burner with chimney.

2. Prepare the system for measurements as described in *Appendix A*.
3. Determine the power P_H of the burner. To do this, weigh the burner with methanol before measurements. Light the burner, set the chimney down upon it and start timing. After taking all measurements and extinguishing the burner, note the elapsed time and re-weigh the burner.



ATTENTION!

The burner may only be lit under the supervision of authorized laboratory personnel.

4. Start the Stirling engine. To do this, set the p-V-n-T meter to measure temperature and wait until ΔT reaches $60\text{ }^\circ\text{C}$, then gently push the engine wheel to the right to start the engine. Wait about 5 minutes for the system to stabilise.

5. Determine the work done by the engine W_{pV} in one cycle.

To do this, estimate the area under the pV diagram shown on the oscilloscope screen.

A description of the proposed method of estimation is found in *Appendix B*.

Conversion scales:

- pressure conversion: $1 \text{ V} = 329 \text{ hPa}$,
 - volume conversion: $1 \text{ V} = 2,4 \text{ cm}^3$.
6. Measure the engine's torque M from 0 to $18 \text{ Nm} \cdot 10^{-3}$ for each division on the scale. To do this, carefully adjusting the torque-meter (1 in *Picture 2*) so as not to oscillate, gradually increase the torque by means of the adjusting screw on the pointer (2 in *Picture 2*). For each value of the torque, note the frequency f and temperatures T_1 and T_2 .



Picture 2. Operating Stirling engine: 1 – torque-meter; 2 – adjustment screw; 3 – measuring scale; 4 – burner with chimney.

7. Calculate the work W_m and mechanical power P_m of the engine, as well as the work of frictional forces W_{fr} during one cycle of engine's operation. Tabulate your results and calculations of part II. using the table proposed below.

Table 1: Example of a table for recording results and calculations.

lp.	f [min^{-1}]	f [s^{-1}]	M [$\text{Nm} \cdot 10^{-3}$]	T_1 [$^{\circ}\text{C}$]	T_2 [$^{\circ}\text{C}$]	ΔT [K]	W_m [mJ]	P_m [mW]	W_{fr} [mJ]

8. Plot a graph of the mechanical work and frictional work as a function of frequency and a graph of mechanical power as a function of frequency. Draw conclusions from your plots.
9. Based on the results of measurements of the maximum mechanical power, calculate:
- a) number of moles of the gas doing work (one should assume $p = 1013 \text{ hPa}$, $V = 38 \text{ cm}^3$);
 - b) mechanical efficiency;
 - c) total efficiency;
 - d) Carnot efficiency.

III. Apparatus.

1. Model of Stirling engine.
2. p-V-n-T meter.
3. Oscilloscope.
4. Torque-meter with measuring-scale.
5. Two thermocouples.
6. Burner with chimney.
7. Stopwatch.

IV. Literature.

1. PHYWE Handbook, „*Laboratory Experiments Physics*”, P2360415 „Stirling Engine”.
2. R.P. Feynman, R.B. Leighton, M. Sands – “*The Feynman Lectures on Physics*”, Wesley 2005.
3. J. Orear – “*Physics*”, Macmillan Publishing Co., Inc., 1979.
4. L.N. Cooper – “*An Introduction to the Meaning and Structure of Physics*”, Harper & Row, 1968.

Appendix A

Preparing the system for taking measurements

I. Preparations include:

1. re-fuelling the burner ;
2. fitting the torque measuring-scale ;
3. connecting the circuit ;
4. starting and calibrating the p-V-n-T meter;
5. starting and configuring the oscilloscope.

II. Re-fuelling the burner.



Picture 3. View of the burner: 1 – screw-cap; 2 - container; 3 - chimney.

1. Pour the fuel (methanol) into the container (2 in Picture 3).
2. Tighten the screw-cap onto the top of the container.

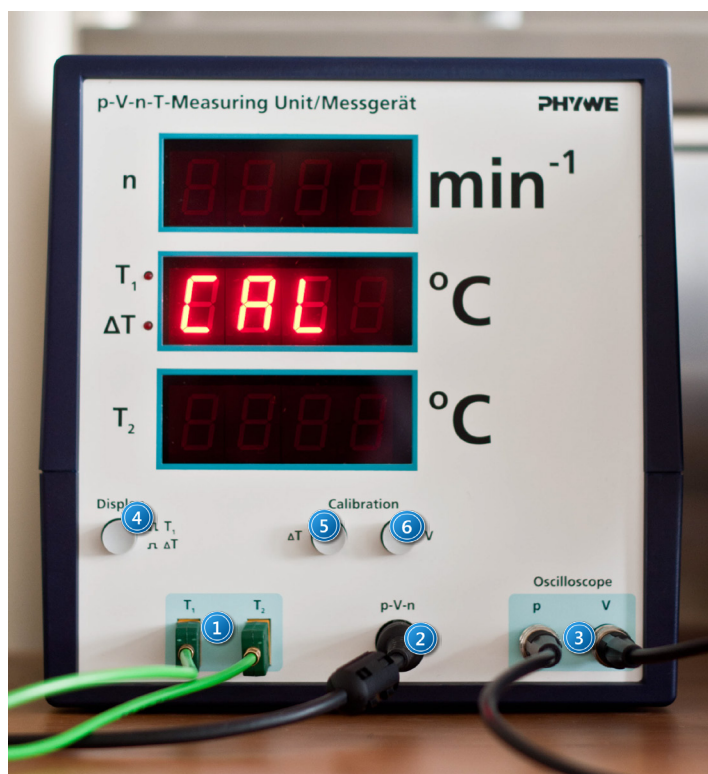


Hint

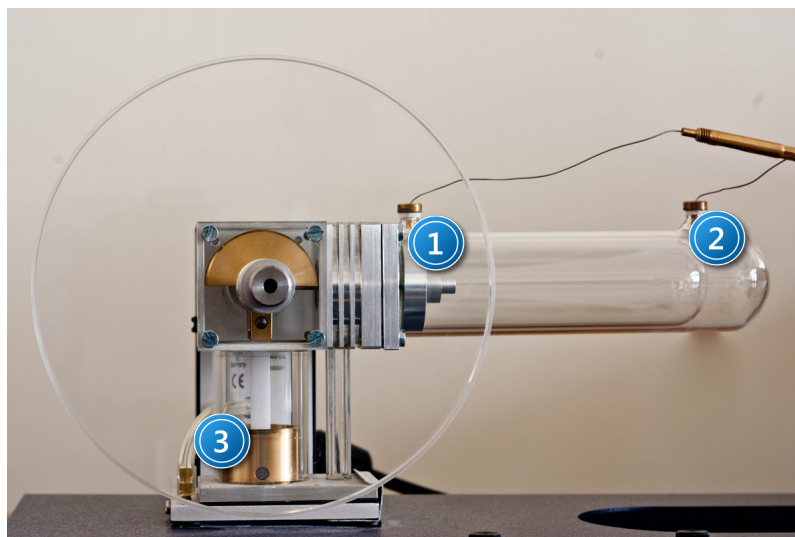
50 ml of methanol is sufficient for approximately one hour of measurements.

III. Connecting the cables.

1. Connect the components of the system using images *Picture 4* and *Picture 5* .



Picture 4. p-V-n-T meter: 1 – thermocouple inputs T_1 , T_2 ; 2 - p-V-n meter cable input; 3 – oscilloscope output p and V ; 4 – temperature display mode selector switch; 5 – temperature calibration dial; 6 – volume calibration dial.



Picture 5. Model Stirling engine with vertical piston in the lower position: 1 – thermocouple T_1 ; 2 – thermocouple T_2 ; 3 – vertical piston in the down position.

2. Connect both thermocouples T_1 and T_2 to their respective inputs on the p-V-n-T meter (1 in *Picture 4*) and the pressure gauge cable p-V-n (2 in *Picture 4*), and the BNC cables to the outputs of the pressure-volume meter (3 in *Picture 4*).

- Connect the BNC cables from the oscilloscope.
Connect the volume channel of the p-V-n-T meter to channel 1 on the oscilloscope, and the pressure channel to channel 2 on the oscilloscope.
- Gently plug the ends of the thermocouples into the metal contacts in *Picture 5*.

IV. Starting and calibrating the p-V-n-T meter.



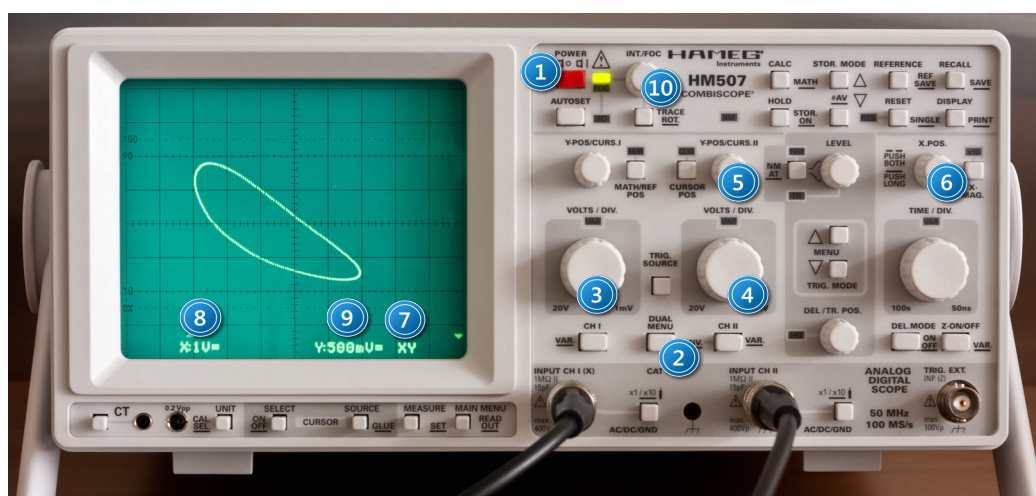
ATTENTION!

The p-V-n-T meter calibration must be carried out at room temperature. If the engine is warm, wait until it cools down.

- Position the engine so that the vertical piston (3 in *Picture 5*) is in its down position.
- Turn on the p-V-n-T meter (switch on the rear wall of the casing).
- Calibrate temperature by pressing the ΔT button on the p-V-n-T meter panel (5 in *Picture 4*), and then calibrate the volume by clicking the ΔV button (6 in *Picture 4*).

V. Starting and configuring the oscilloscope.

- Turn on the oscilloscope by pressing the red *POWER* button (1 in *Picture 6*).



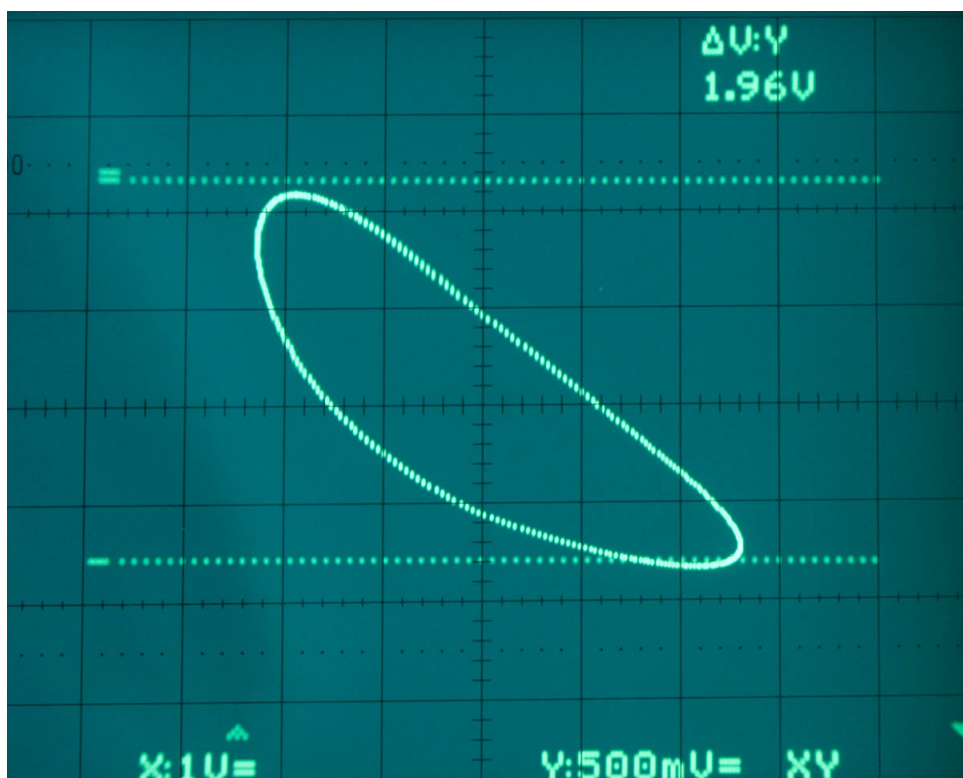
Picture 6. View of the front panel of the oscilloscope: 1 – power switch; 2 – mode switch; 3, 4 – channel gain dials; 5, 6 – channel offset dial; 7 - current operating mode; 8, 9 – current channel gain; 10 – brightness dial.

- Using the gain dials (3, 4 in *Picture 6*), set the gain for channel 1 to 500 mV and for channel 2 to 1 V.
The current gain is displayed on the oscilloscope screen (8 and 9 in *Picture 6*).
- Put the oscilloscope in XY mode by repeatedly pressing the *DUAL MODE* button (2 in *Picture 6*), until XY is displayed on the oscilloscope screen (7 in *Picture 6*).
- Using the offset dials (5 and 6 in *Picture 6*), centre the dot on the oscilloscope screen.

Appendix B

Methods to estimate the area under PV curves

A typical oscillogram is shown in *Picture 7*.



Picture 7. Oscillogram.

A simple and convenient way to estimate the area under the pV diagram is to count how many squares lie within the curve.

The area of each square is $\Delta V_x \times \Delta V_y$, and the conversions from voltage to pressure and volume are:

- pressure conversion: $1 \text{ V} = 329 \text{ hPa}$;
- volume conversion: $1 \text{ V} = 2,4 \text{ cm}^3$.

The total area under the curve is equal to the product of the area of one square with the estimated number of squares.