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Experiment 9

Study to determine the characteristics of a Stirling engine (Cobra version)

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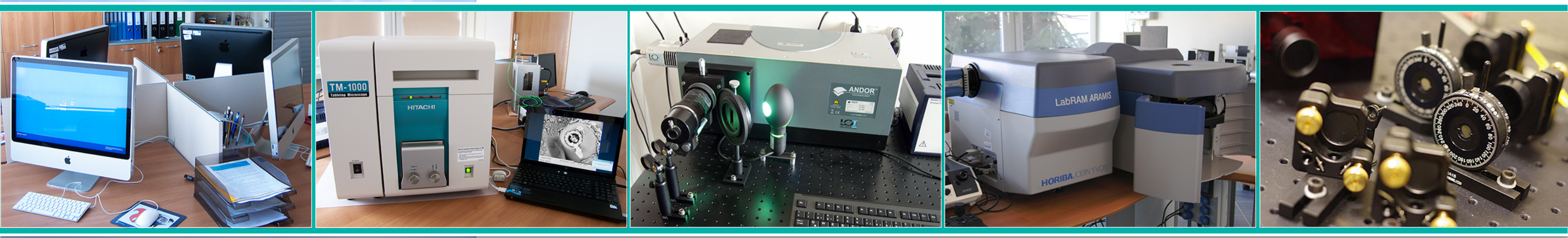
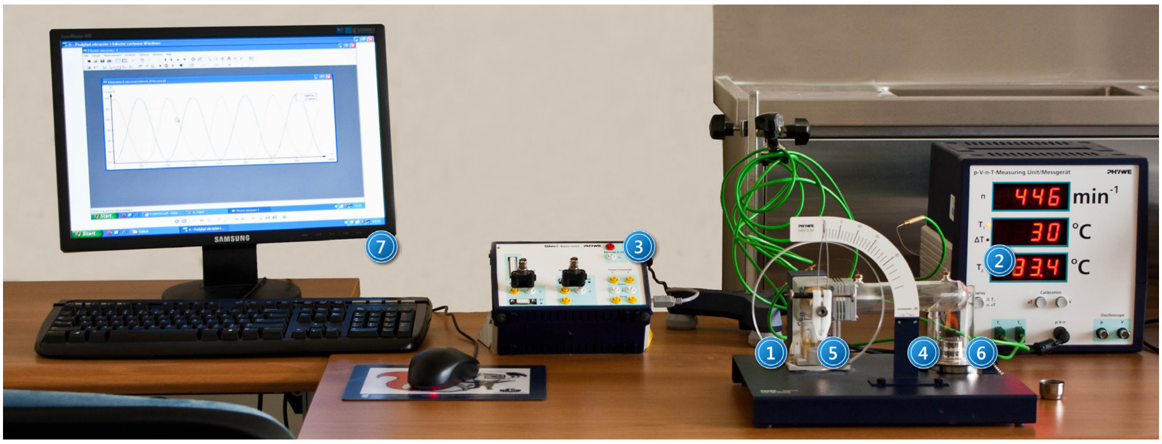


I. Background theory.

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 and Cobra 3 module: 1 – Stirling engine model; 2 –p-V-n-T meter; 3 – Cobra 3 measurement module ; 4 – torque measuring scale; 5 - torque-meter; 6 - burner with chimney; 7 - computer.

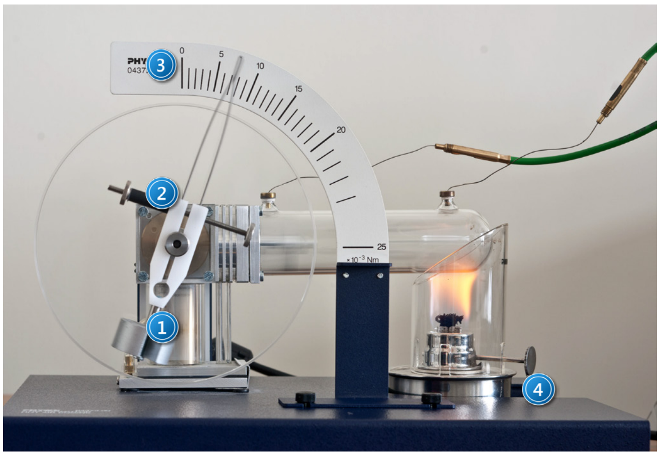
2. Prepare the system for measurements as described in *Appendix A*.
3. Determine the power P_H of the burner. To do this, weigh the burner with methanol before measurements. Light the burner, set the chimney down upon it and start timing.
   After taking all measurements and extinguishing the burner,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

ATTENTION!

The burner may only be lit under the supervision of authorised 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 ^{O}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, use the application Phywe Measure 4 as described in *Appendix B*.
   Conversion scales:
   - pressure conversion: 1 V = 329 hPa,
   - volume conversion: 1 V = 2,4 cm^3.

6. Measure the engine's torque M from 0 to 18 Nm*10^{-3} for each division on the scale (3 in *Picture 2*). 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 1. 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 of calculations.

lp.	f [min^{-1}]	f [s^{-1}]	M [Nm^x10^{-3}]	T_1 [˚C]	T_2 [˚C]	ΔT [K]	W_m [mJ]	P_m [mW]	W_{fr} [mJ]

8. Plot a graph of mechanical work and work done by friction forces as a function of frequency and mechanical power as a function of frequency.
   Draw conclusions from your graphs.
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 hPa, V = 38 cm^3);
   b) mechanical efficiency;
   c) total efficiency;
   d) Carnot efficiency.

III. Apparatus.

1. Model Stirling engine.
2. p-V-n-T meter.
3. Oscilloscope.
4. Torque-meter with measuring-scale.
5. Two thermocouples.
6. Burner with chimney.
7. Cobra 3 module.
8. Computer.
9. 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.

II. Re-fuelling the burner.

1. Pour the fuel (methanol) into the container (2 in *Picture 3*).

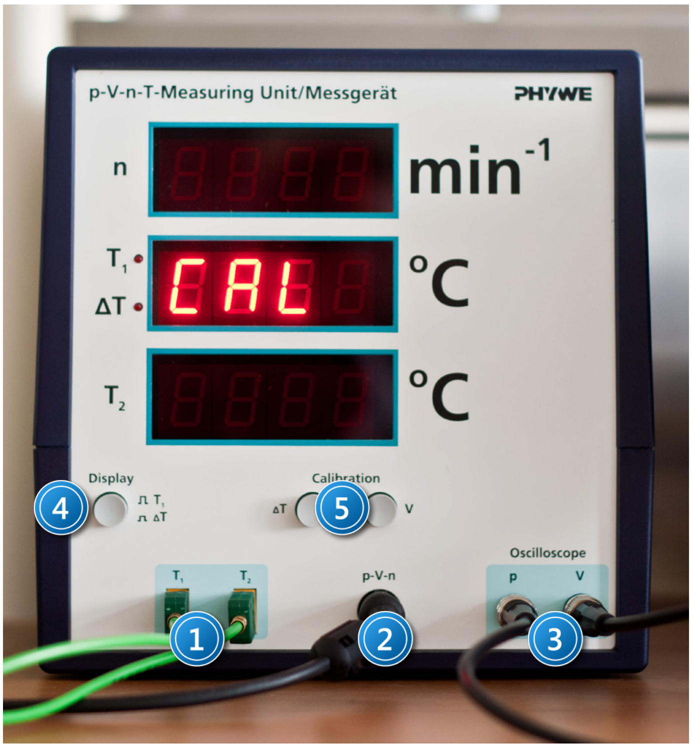
Picture 2. View of the burner: 1 – screw-cap; 2 - container; 3 - chimney.

2. Tighten the screw-cap onto the top of the container.

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

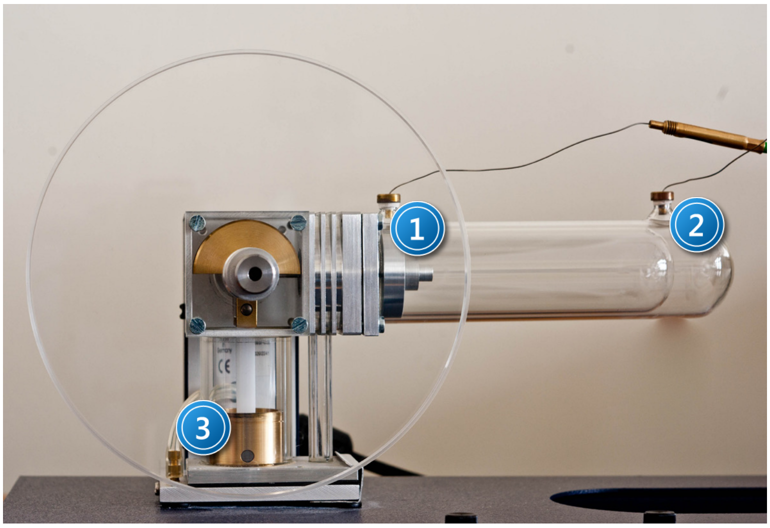
III. Connecting the cables.

1. Connect both thermocouples to the p-V-n-T measuring unit inputs T_1 and T_2 (1 in *Picture 4*) and the p-V-n cable (2 in *Picture 4*), as well as the BNC cables to the pressure and volume outputs (3 in *Picture 4*).



Picture 3. 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 and volume calibration buttons.

2. Carefully insert the tips of the thermocouples into the metal tabs on the horizontal cylinder of the engine as shown in *Picture 5*.



Picture 4. 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.

3. Connect the BNC cables to the Cobra 3 measuring unit.

   Connect the volume channel of the p-V-n-T meter to Analog IN 1/S1 (1 in *Picture 6*) and the pressure channel to Analog IN 2/S2 (2 in *Picture 6*) of the Cobra 3 measuring unit.

Picture 6. Cobra 3 measuring unit: 1 – input Analog In 1; 2 - input Analog In 2.

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.

1. Position the engine so that the vertical piston (3 in *Picture 5*) is in its down position.
2. Turn on the p-V-n-T meter (switch on the rear wall of the casing).
3. 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*).

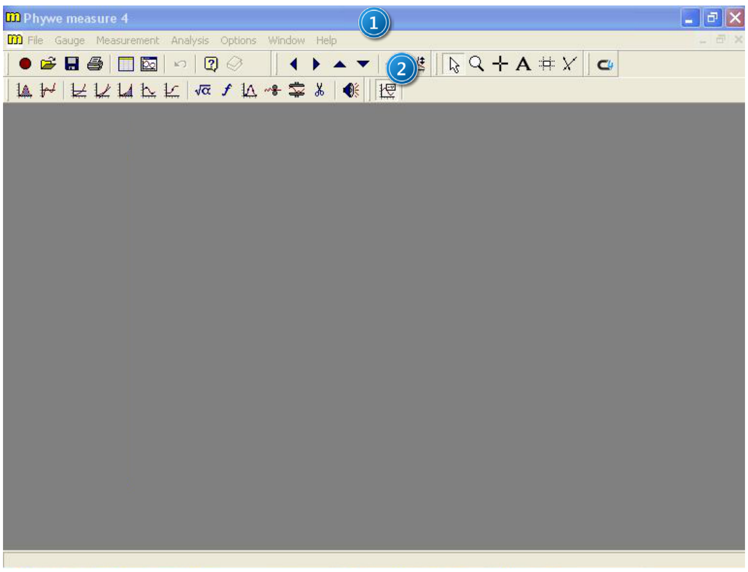
Appendix B

The Cobra 3 measuring module software

I. Recording measurements on the computer.

1. Start the program Cobra 3 by clicking on the *measure* icon found on the desktop (*Picture 7*). You will see the program *Phywe Measure 4 (Picture 8*).

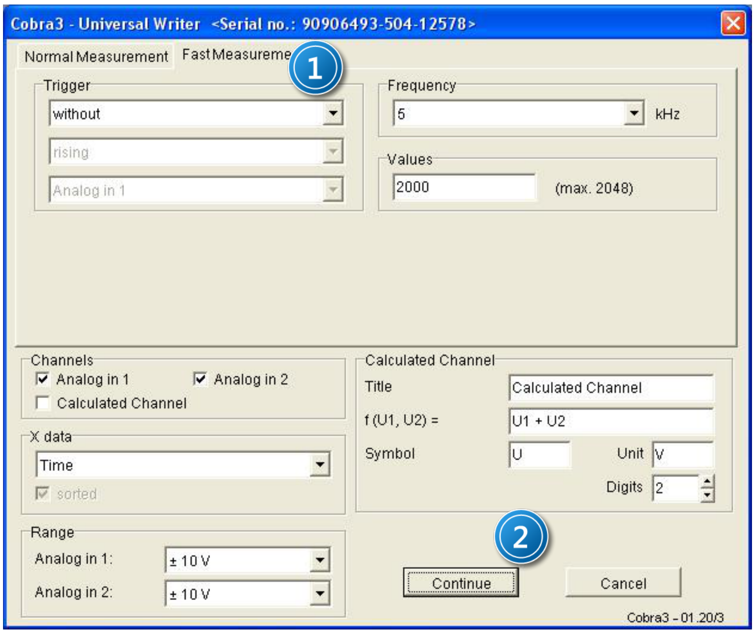
Picture 7. View of the desktop: 1 – measure icon.



Picture 8. Main window of Phywe Measure 4: 1 – program menu; 2 - toolbar.

2. Start the measurement wizard by clicking *Measurement > Universal Writer*. A window will be shown titled: *Cobra 3 – Universal Writer* (*Picture 9)*.

3. In the *Cobra 3 – Universal Writer* window (*Picture 9*), select the tab *Fast Measurement* (1 in *Picture 9*), then set all options as in *Picture 9* and confirm changes by clicking *Continue* (2 in *Picture 9*). You will see the following screen: *Cobra 3 – measuring* (*Picture 10*).

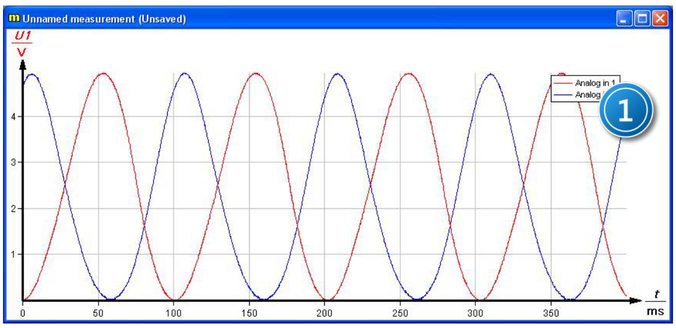


Picture 9. Cobra 3 window: - Universal Writer: 1 - Fast Measurement tab; 2 – confirm changes.

Picture 10. Cobra 3 – measuring window: 1 – start measurements button; 2 – stop measurements button.

4. Click *Start measurement* (1 in *Picture 10*).

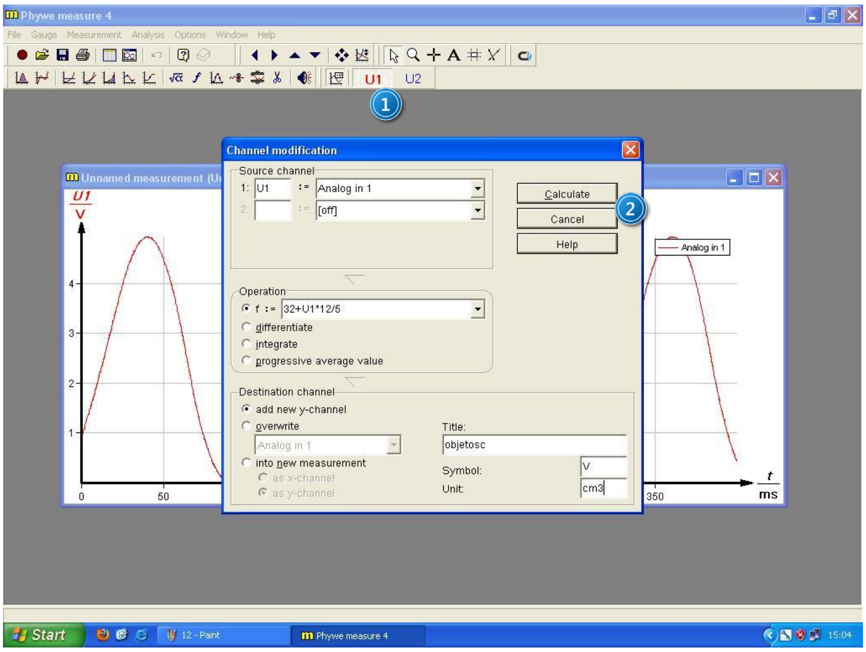
   Stop the measurements after about 10 seconds by clicking *Stop measurement* (2 in *Picture 10*). After taking measurements, a screen will appear with curves from both measurement channels (*Picture 11*).



Picture 11. Graph of recorded results: 1 – channel name.

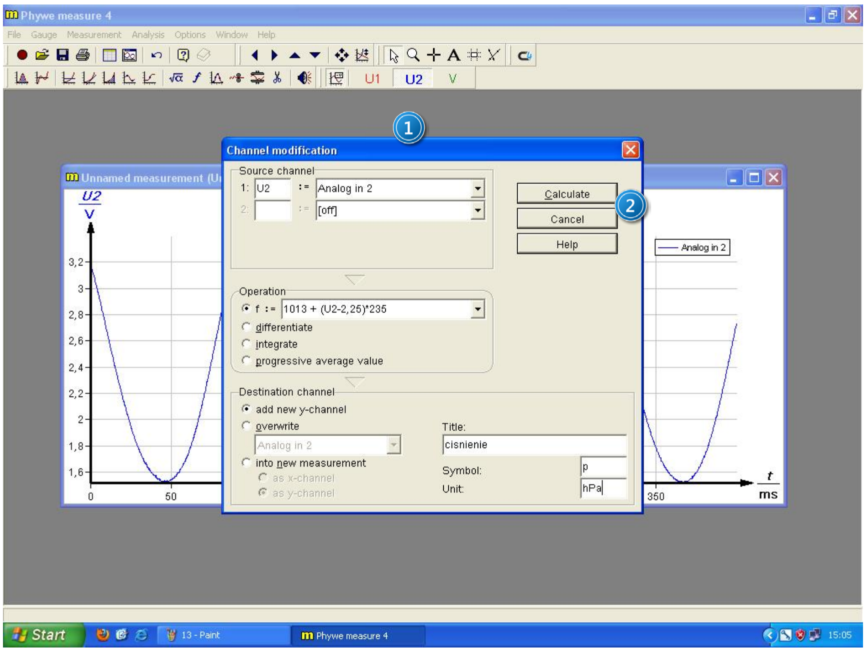
II. Data analysis and determination of block size.

1. Select only U_1 from the channel list and choose the option *Analysis-> Channel Modification*, to adjust the measured voltage to the cylinder volume (as shown in *Pictures 12* and *13*).



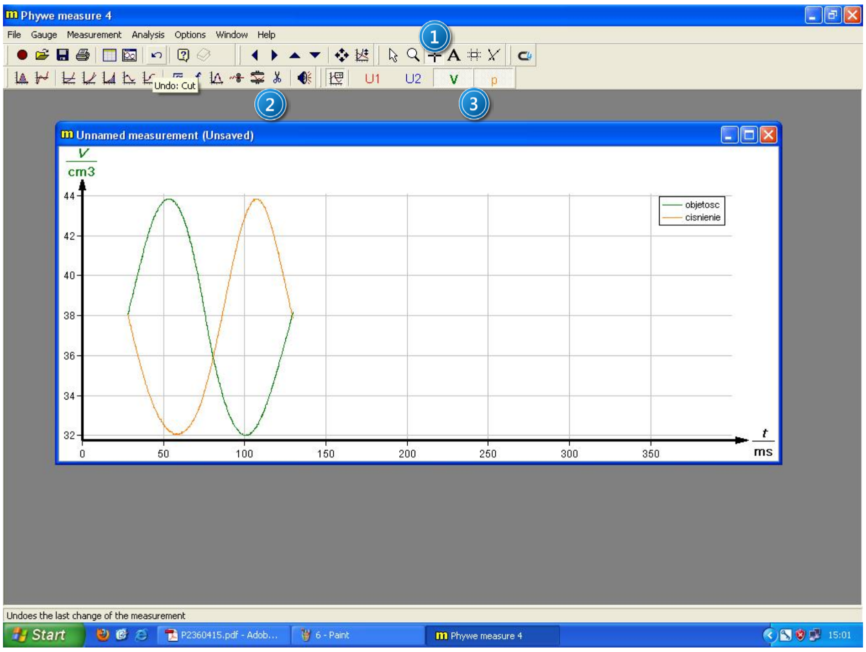
Picture 12. Window for voltage-volume conversion: 1 – selected channel U1; 2 – confirm changes button.

Confirm the changes by clicking *Calculate (2* in *Picture 12*).
Repeat the operation for the pressure channel U_2 (*Picture 13*).



Picture 13. Window for voltage-volume conversion: 1 – selected channel U2; 2 – confirm changes button.

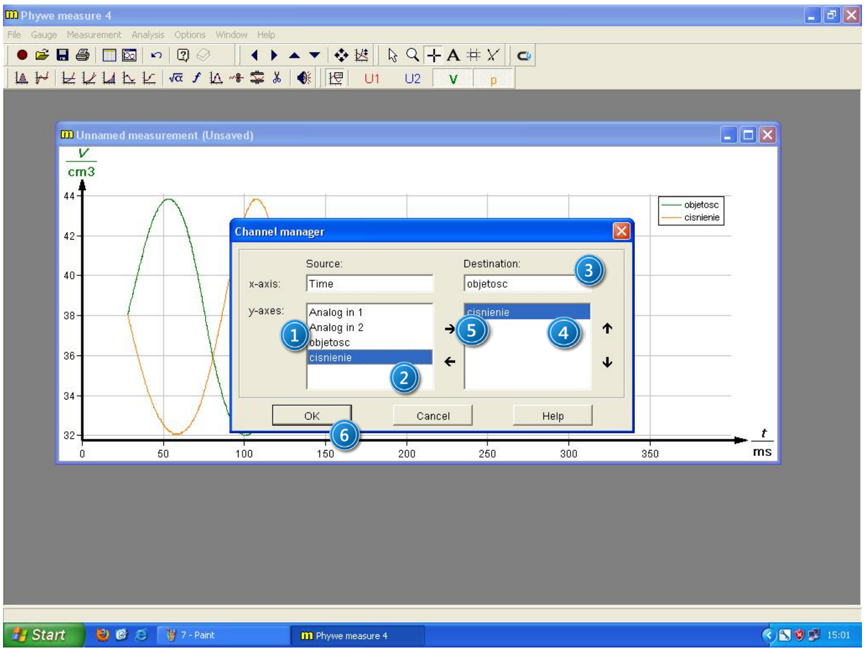
2. Crop the plot such that only a single cycle of the engine is shown. To do this, select the pressure-volume display (3 in *Picture 14*) and select the *mark tool* (1 in *Picture 14*) from the toolbar, select the unwanted parts and select *cut* (2 in *Picture 14*).



Picture 14. A single engine cycle: 1 – Mark tool; 2 – Cut tool; 3 – selected channels V and p.

3. Switch the measurements display to XY mode by using the option *Analysis* → *Channel Manager*.

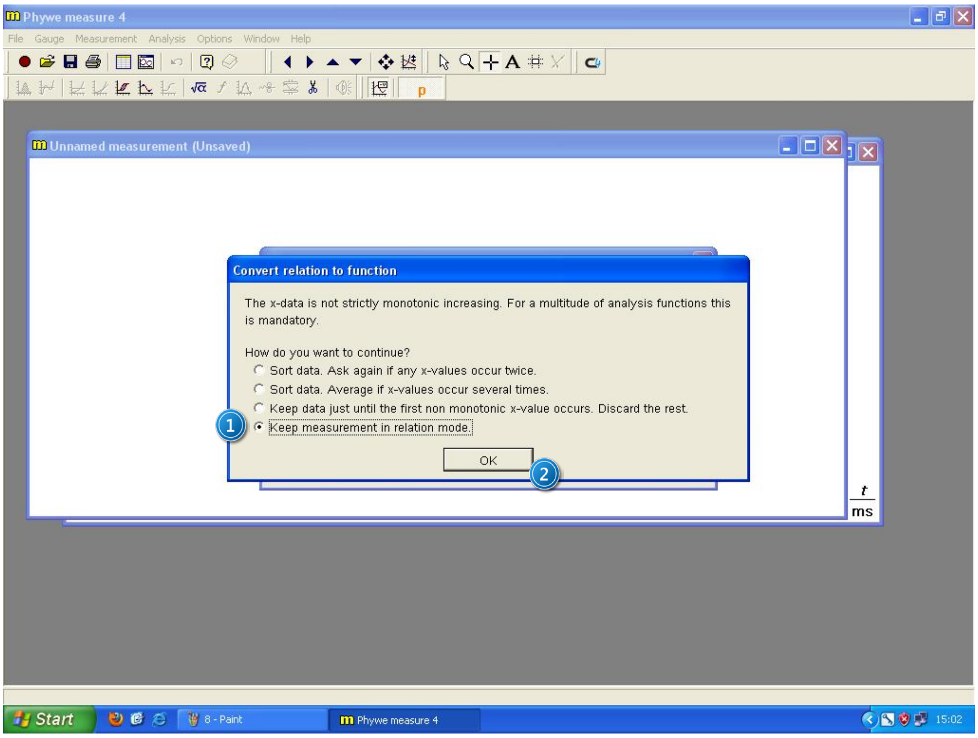
   In the *Chanel manager* window, select the volume channel (1 in *Picture 15*) and click the button (5 in *Picture 15*). The X axis should be associated with volume (3 in *Picture 15*).



Picture 15. Graph transformation in XY mode: 1 – volume channel; 2 - pressure channel; 3 – assign channel to X axis; 4 – assign channel to Y axis; 5 – select channel; 6 – save changes.

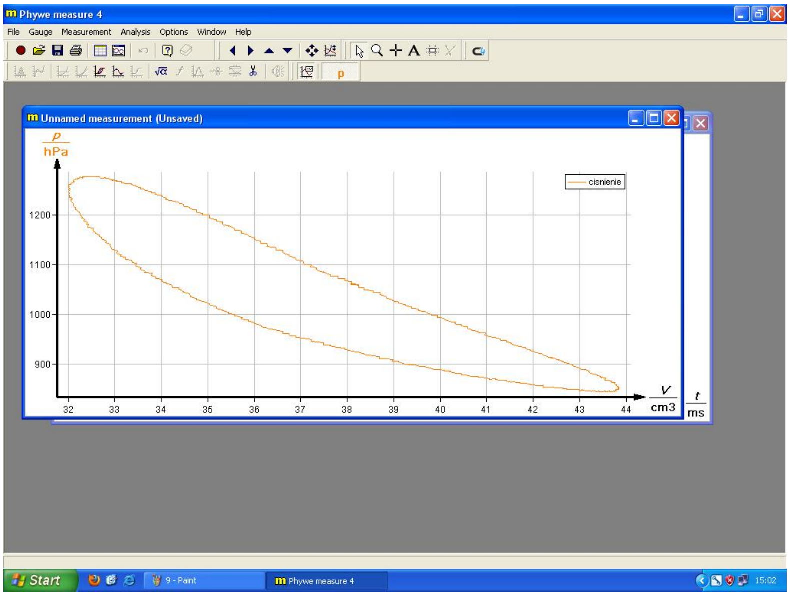
Repeat the operation for the pressure channel (2 in *Picture 15*).
The correct axis assignment is shown in *Picture 15*.
After completing the set-up, click OK. (6 in *Picture 15*).

4. Choose the option *Keep measurement in relation mode* (1 in *Picture 16*) and confirm by clicking *OK* (2 in *Picture 16*).



Picture 16. Setting the relationship between the channels U_1 and U_2: 1 - Keep measurement in relation mode option; 2 – confirm changes.

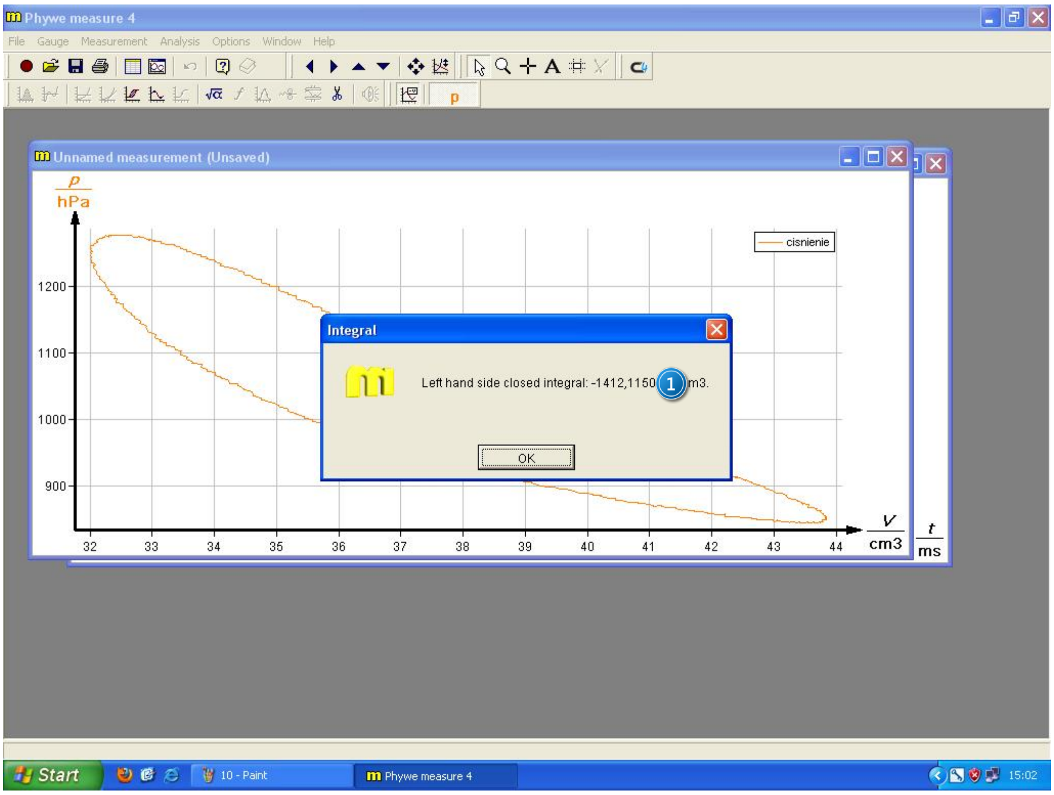
A graph of pressure vs. volume will be shown p = f(V) (*Picture 17*).



Picture 17. Correctly obtained pV diagram.

5. Determine the area under the pV diagram by choosing the menu option *Analysis → Show integral*.

   You will see a box with the relevant pV diagram (*Picture 18*).



Picture 18. The area under the pV diagram: 1 – field value.