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General information

Application

PHYWE Stirling engine transparent 04372-00

PHYWE's transparent Stirling engine combines the following features:

- Completely transparent - all important parts are visible
- Measurement of all experimental data through USB SmartSense module
- measureLAB compatible
- Large transparent flywheel.
- Both cylinder and displacement piston made of heatproof glass.
- Displacement piston with 2 measuring connecting pieces for temperature measurements.

Application

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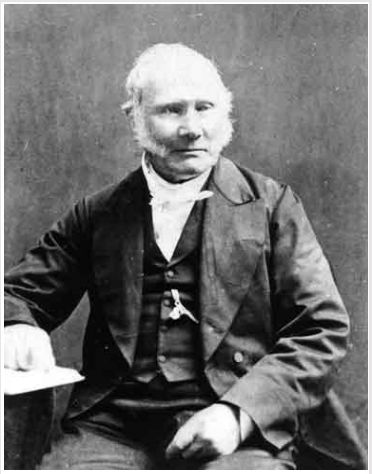
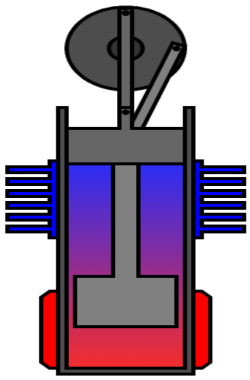


Dr. Robert Stirling

A Stirling engine is a heat engine that is operated by a cyclic compression and expansion of air at different temperatures, such that there is a net conversion of heat energy to mechanical work. More specifically, the Stirling engine is a closed-cycle regenerative heat engine with a permanently gaseous working fluid.

The Stirling engine was originally designed by Dr. Robert Stirling (1790 – 1878).

Application



Principle of the Sterling Engine

PHYWE's Stirling engine has only one cylinder, hot at one end and cold at the other. A loose-fitting displacer shunts the air between the hot and cold ends of the cylinder. A power piston at the open end of the cylinder drives the flywheel.

Other information (1/2)

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Prior knowledge

Scientific principle

The cycle consists of four thermodynamic processes / Carnot circle

- Isothermal heat addition (expansion).
- Isochoric heat removal (constant volume).
- Isothermal heat removal (compression).
- Isochoric heat addition (constant volume).

Wheras the Stirling circle have perpendicular lines, in real applications as PHYWE's Stirling Engine this cycle is quasi-elliptical.

Other information (2/2)

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Learning objective

What you can learn about …

- First and second law of thermodynamics
- Reversible cycles Isochoric and isothermal changes
- Gas laws
- Efficiency
- Conversion of heat
- Thermal pump
- Carnot cycle

Principle

The Stirling engine is submitted to a load by means of an adjustable torque meter, or by a coupled generator. Rotation frequency and temperature changes of the Stirling engine are observed. Effective mechanical energy and power, as well as effective electrical power, are assessed as a function of rotation frequency. The amount of energy converted to work per cycle can be determined with the assistance of the pV diagram.

The efficiency of the Stirling engine can be estimated.

Safety instructions

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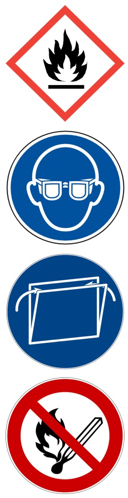


- **Ethanol / Denaturated alcohol**

  For this experiment the general instructions for safe experimentation in science lessons apply.

  For H- and P-phrases please consult the safety data sheet of the respective chemical.

  H225: Highly flammable liquid and vapour.

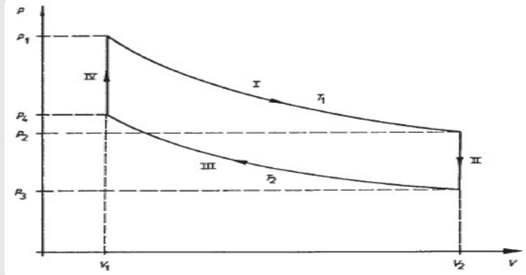
  H318: Causes serious eye damage.

  P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking

Theory (1/6)

In 1816, Robert Stirling was granted a patent for a hot air engine, which is known today as the Stirling engine. In our times, the Stirling engine is used to study the principle of thermal engines because in this case the conversion process of thermal energy to mechanical energy is particularly clear and relatively easy to understand.
At present, the Stirling engine is undergoing a new phase of further development due to its many advantages.
Thus, for example, it constitutes a closed system, it runs very smoothly, and it can be operated with many different heat sources, which allows to take environmental aspects into consideration, too.

Theoretically, there are four phases during each engine cycle.



pV diagram for the ideal Stirling process

Theory (2/6)

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I) An isothermal modification when heat is supplied and work produced: $V_1 \rightarrow V_2; p_1 \rightarrow p_2; T_1 = const.$

II) An isochoric modification when the gas is cooled: $T_1 \rightarrow T_2; p_2 \rightarrow p_3; V_2 = const.$

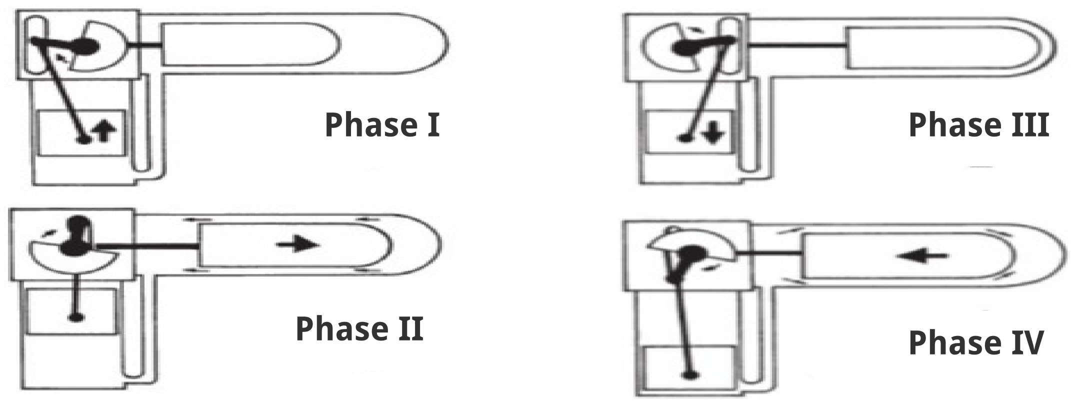
III) An isothermal modification when heat is produced and work supplied: $V_2 \rightarrow V_1;\ p_3 \rightarrow p_4;\ T_2 = const.$

IV) An isochoric modification when heat is supplied to the system: $T_2 \rightarrow T_1; p_4 \rightarrow p_1; V_1 = const$

According to the first law of thermodynamics, when thermal energy is supplied to an isolated system, its amount is equal to the sum of the internal energy in- crease of the system and the mechanical work supplied by the latter:

$$dQ = dU + pdV$$

It is important for the Stirling cycle that the thermal energy produced during the isochoric cooling phase be stored until it can be used again during the isochoric heating phase (regeneration principle).



Functioning of the Stirling engine, Phase I, II, III, IV

Theory (4/6)

Thus, during phase IV the amount of thermal energy released during phase II is regeneratively absorbed. This means that only an exchange of thermal energy takes place within the engine. Mechanical work is merely supplied during phases I and III. Due to the fact that internal energy is not modified during isothermal processes, work performed during these phases is respectively equal to the absorbed or released thermal energy.

Since

$$p \cdot V = \nu \cdot R \cdot T$$

where ν is the number of moles contained in the system, and R the general gas constant.

The amount of work produced during phase I is:

$$W_1 = -n \cdot R \cdot T_1 \cdot ln(V_2/V_1)$$

(negative, because this amount of work is supplied).

Consequently, the amount of work supplied during phase III is:

$$W_3 = +\nu \cdot R \cdot T_2 \cdot ln(V_2/V_1)$$

$|W_1| > W_3$ because $T_1 > T_2$

Theory (5/6)

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Consequently, the amount of work supplied during phase III is

$$W_3 = +\nu \cdot R \cdot T_2 \cdot ln(V_2/V_1)$$

$|W_1| > W_3$ because $T_1 > T_2$

The total amount of work is thus given by the sum of W_1 and W_3 . This is equal to the area of the pV diagram:

$$W_t = W_1 + W_3$$

$$W_1 = -\nu \cdot R \cdot (T_1 - T_2) \cdot ln(V_2/V_1)$$

Only part of this total effective energy W_t is used as effective work W_m through exterior loads applied to the engine. The rest contains losses within the Stirling engine.

The maximum thermal efficiency of a reversible process within a thermal engine is equal to the ratio between the total amount of work W_1 and the amount of supplied thermal energy $Q_1 = -W_1$

$$\eta_{th} = W_t/W_1$$

$$\eta_{th} = \frac{\nu \cdot R \cdot (T_1 - T_2) \cdot ln(V_2/V_1)}{\nu \cdot R \cdot T_1 \cdot ln(V_2/V_1)}$$

$$\eta_{th} = \frac{T_1 - T_2}{T_1}$$

Carnot found this to be the maximum thermal efficiency for any thermal engine, which can only be reached theoretically. One sees that efficiency increases with increasing temperature differences.

Theory (6/6)

Only part of this total effective energy W_t can be used as effective work W_m through exterior loads applied to the engine.

The remaining part contains losses within the Stirling engine.

The maximum thermal efficiency of a reversible process within a thermal engine is equal to the ratio between the total amount of work $|W_1|$ and the amount of supplied thermal energy $Q_1 = -W_1$

$$\eta_{th} = W_t/W_1$$

$$\eta_{th} = \frac{\nu \cdot R \cdot (T_1 - T_2) \cdot ln(V_2/V_1)}{\nu \cdot R \cdot T_1 \cdot ln(V_2/V_1)}$$

$$\eta_{th} = \frac{(T_1 - T_2)}{T_1}$$

Carnot found this to be the maximum thermal efficiency for any thermal engine, which can only be reached theoretically.
Efficiency increases with increasing temperature differences.

Equipment

Position	Material	Quantity
1	Graduated cylinder, 50 ml, plastic	1
2	Denaturated alcohol (spirit for burning), 1000 ml	1
3	curricuLAB measureLAB, multi-user license	1
4	Connecting cord, 32 A, 500 mm, blue	3
5	Connecting cord, 32 A, 500 mm, red	2
6	Digital Multimeter, 2.000 Counts, 600V AC/DC, 10A, with NiCr-Ni thermocouple and inductance measurement	2
7	Lamp 4 V/0.1 A, E10	5
8	Rheostat, 330 Ohm , 1.0A	1
9	Stirling Engine Datalogging Module	1
10	Chimney for stirling engine	1

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Setup and procedure

Tasks

Tasks

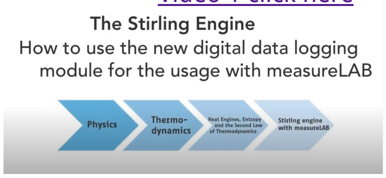
- Setup of the experiment
- Calculation of the total energy produced by the Sterling engine
- Assessment of the mechanical work per revolution, and calculation of the mechanical power output as a function of the rotation frequency, with the assistance of the torque meter.
- Determination of the burner’s thermal efficiency
- Assessment of the electric power output as a function of the rotation frequency.
- Efficiency assessment.

Setup (1/2)

Videos for setup the experiment

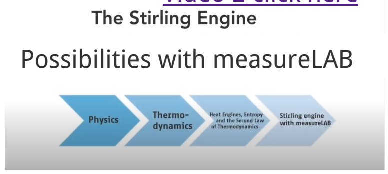
in an easy way you may perform the setup following the included video.

[Video 1 click here]



**The Stirling Engine:
How to mount the data logging module for the usage with measureLAB**

[Video 2 click here]



**The Stirling Engine:
Possibilities with measureLAB**

[Video 3 click here]

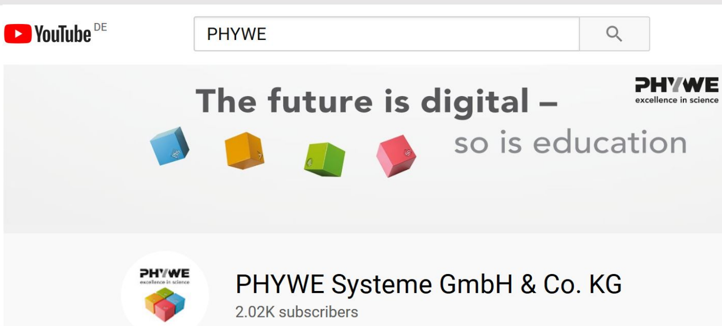
**The Stirling Engine:
Marketing**

Setup (1/X)

Please also sign up for the YouTube PHYWE channel

You never will miss in future new info for relevant purposes

https://www.youtube.com/c/phywesysteme/featured to subscribe just click here



Procedure

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Experiment for volume thermal expansion

The change in volume is read from the scale on the tube built into its stopper.

Experiment for linear thermal expansion

Clamp on the measuring tube, set the scale on the dial gauge to “0” and measure the expansion as a function of the temperature. There is so little expansion in the case of duran glass and quartz glass that the heating and expansion of the dilatometer body as a result of radiation and conduction falsifies the measurement considerably. In this case, therefore, the measurement is started at the highest temperature (80 °C) and the hot water in the bath replaced with cold tap water.

Experiment for linear dimensional change

In the case of aluminium, expansion is measured at three different rod lenghts. The rod can be clamped in various places for this.

Evaluation (1/X)

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Spirit burner, adjustable 32154-00

Estimation of the thermal power of the burner (see photo) is given below.

Amount of alcohol burned $\Delta V = 29ml$

Alcohol density $\rho = 0.83g/ml$

This allows to determine the mass of alcohol burnt per second:

$$\frac{\Delta m}{\Delta t} = 6.69 \cdot 10^{-3}\ \mathrm{g/s}$$

as well as the thermal power of the burner:

$$P_H = 167\ \mathrm{W}$$

Evaluation (2/X)

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Experiment for volume thermal expansion

	Materials	$\alpha / 10^{-3} K^{-1}$
a	Ethyl acetate	1.37
b	Methylated spirit	1.11
c	Olive oil	0.72
d	Glycerol	0.50
e	Water	0.20

Measured coefficient of volume expansion

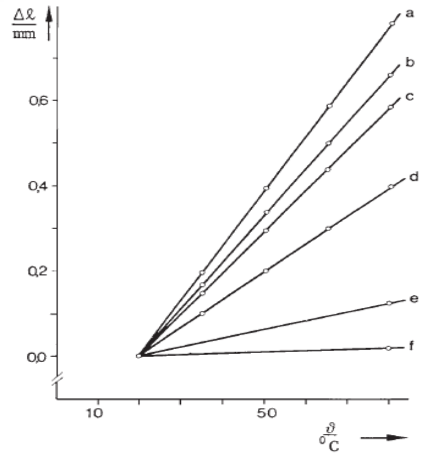
Relationship between volume V and temperature θ

Evaluation (3/X)

Experiment for linear thermal expansion

	Materials	$\alpha/10^{-3}K^{-1}$
a	Aluminium	2.2
b	Brass	1.8
c	Copper	1.6
d	Stell	1.1
e	Duran glass	0.32
f	Quartz glass	0.046

Measured coefficients of linear expansion



Relationship between length l and temperature θ

Evaluation (4/X)

Experiment for linear dimensional change

If the temperature changes $\Delta\theta$ are not too large, the change in length Δl is proportional to the original length l_0

Change in length Δl as a function of the original length l_0 for aluminium

Evaluation (5/X)

Describe about the thermal expansion:

temperature | lower | decrease | high | coefficient expansion

In general, thermal expansion is the tendency of matter to change in volume in response to ___ alterations, which can be described by the volume ___. It describes a fractional change in length or volume per unit temperature change. Thermal expansion generally ___ with increasing bond energy, which also has an effect on the melting point of solids. So, ___ melting point materials are more likely to have ___ thermal expansion.

Check

Evaluation (6/X)

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Which statements are correct to explain thermal expansion of solid?

- [ ] The thermal stress of solid is proportional to the change in temperature
- [ ] Volumetric expansion coefficient is usually used in describing the expansion of solid
- [ ] The expansion of solid is uniform in all dimensions for an isotropic material
- [ ] Thermal expansion generally decrease with increasing bond energy

Check

Other information (2/2)

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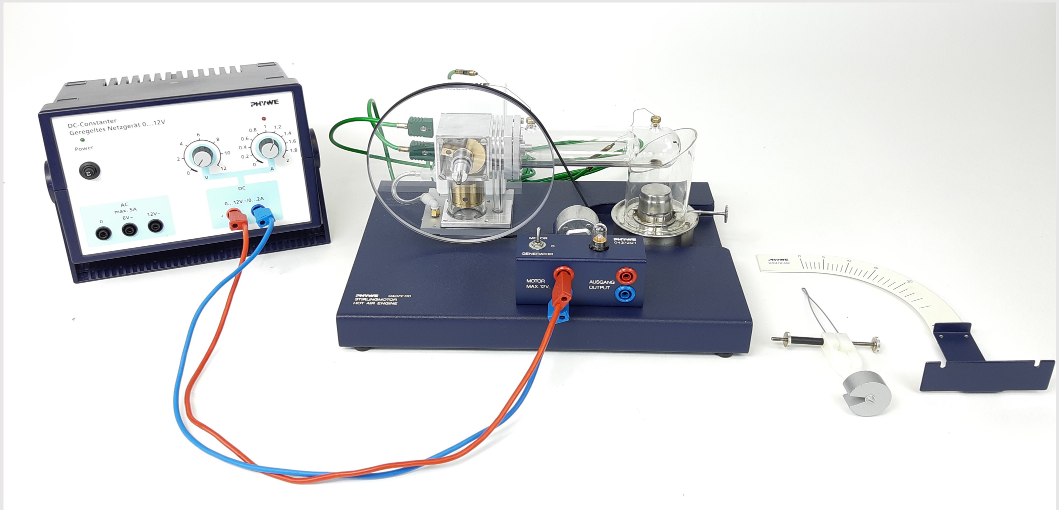
Experimental setup



Slide	Score/Total
Slide 25: Thermal expansion expansion	**0/5**
Slide 26: Thermal expansion of solid	**0/3**

Total Score 0/8

Show solutions Retry