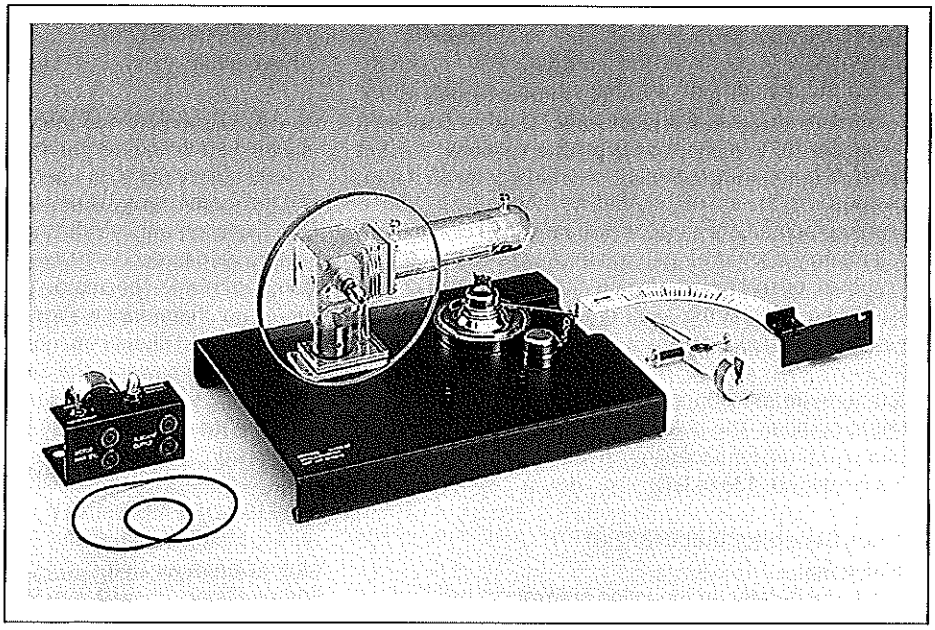
PHYWE

Stirling Motor, transparent
Motor/Generator Unit
Torque Meter

04372.00
04372.01
04372.02

Operating instructions



1 PURPOSE AND CHARACTERISTIC PROPERTIES

A Stirling motor (hot-air motor) converts heat energy into mechanical energy. When driven mechanically it acts as a heat pump or refrigerating machine and therefore impressively demonstrates the reversibility of thermodynamic processes. The operating principle of the Stirling motor is explained in Fig. 2.

The main and displacement pistons are mounted in a 90° V-type configuration. The main piston (A) is made of metal and fits exactly in the glass tube. The glass displacement piston (V) also provides the regenerator function which is important for the operation of the Stirling motor. It cools the hot gas which flows past it, stores its energy and passes the energy on to the returning cold gas.

The mechanical energy produced by the Stirling motor is converted into electrical energy in the form of light with the aid of a motor/generator unit. The Stirling motor can therefore also be mechanically driven.

The Stirling motor can be loaded with a certain torque using the torque meter. If the speed is also measured, the mechanical power produced can be computed.

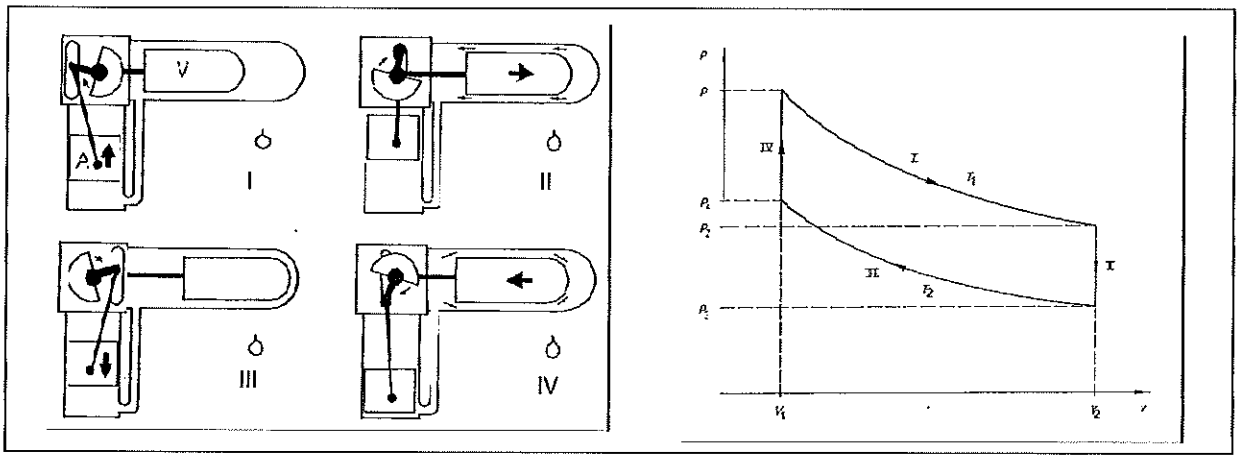


Fig. 2: Operating principle of the Stirling motor

1) Isothermal expansion, heat absorbed, work done — $V_1 \rightarrow V_2$ $p_1 \rightarrow p_2$ and T_1 = constant.
2) Isochoric heat emission, no work transferred — $T_1 \rightarrow T_2$ $p_2 \rightarrow p_3$ and V_2 = constant.
3) Isothermal compression, heat emission, work absorbed — $V_2 \rightarrow V_1$ $p_3 \rightarrow p_4$ and T_2 = constant.
4) Isochoric heat absorption, no work transferred — $T_2 \rightarrow T_1$ $p_4 \rightarrow p_1$ and V_1 = constant.

2 DESCRIPTION AND OPERATION

2.1 Stirling Motor 04372.00

Supplied items:

1 Stirling motor
1 blue base plate
1 spirit burner
1 Allen key
4 knurled screws
(2 in base plate, 2 on Stirling motor)

The Stirling motor is placed on the base plate and firmly screwed from the bottom with two knurled screws. Two other knurled screws on top of the base plate are used to attach the motor/generator unit or the torque meter scale.
The flywheel normally remains fastened to the shaft. It can be loosened with the aid of the Allen key. After the flywheel has been remounted, the shaft should be pulled slightly outwards and only a small air gap the thickness of a sheet of paper should be present between the flywheel and the motor housing, so that the shaft does not have too much play when in operation.

Two temperature measuring points are situated in the displacement cylinder. The holes in the metal sleeves have a diameter of 0.6mm for accepting sheathed NiCr/Ni thermocouples (Order no. 13615.01).

2.2 Motor/Generator unit 04372.01

Supplied items:

1 motor/generator on mounting bracket
1 belt
1 filament lamp 4V/40mA

The M/G unit has two pulleys of different size with which the influence of the transmission ratio on the power and speed of the Stirling motor can be demonstrated. A belt links the flywheel to the motor.
The motor and generator operating modes are selected with a switch.
In the generator mode the filament lamp lights. Two output sockets are wired in parallel to the lamp socket, enabling a variable resistance to be connected.
The generator is unloaded with the switch in position „0".
For operation as a motor a DC voltage is applied to the input sockets.

2.3 Torque Meter 04372.02

Supplied items:

1 pointer
1 scale

The inner metal part of the pointer (Prony brake with inclination weight) is fastened to the shaft of the Stirling motor in front of the flywheel using the Allen key. The friction between the metal part and the pointer can be changed with the adjustment screw on the pointer.

When the Stirling motor runs, the pointer is carefully pushed onto the shaft. The friction should then be slowly increased; it should not be so high that motor comes to rest. The set torque is indicated on the scale.

3 TECHNICAL DATA

Stirling motor	
No-load speed	at least 800rpm
Max. power	approx. 1W
M/G unit	
Motor voltage	max. 12VDC
Filament lamp	4V/40mA
Belt diameter	150 mm
Torque meter	
Measurement range	$25 \cdot 10^{-3}$Nm
Resolution	$1 \cdot 10^{-3}$Nm

4 IMPORTANT INFORMATION

The main piston should not be oiled. It has been fitted exactly to the glass cylinder. Oil would lead to increased friction and the motor power would be reduced.
The displacement cylinder has been mounted such that a uniform air gap occurs between it and the displacement piston, optimising the motor power. The fastening screws should not therefore be altered.
The piston rod should be lubricated with a drop of thin machine oil if the power of the Stirling motor drops. This is best done using a syringe (Order no. 02593.03) with a hollow needle (Order no. 02597.04), so that no oil drops onto the main piston.

5 LIST OF EQUIPMENT

Stirling Motor, transparent	04372.00
Motor/Generator Unit	04372.01
Torque Meter	04372.02
Accessory for solar motor operation	04372.03
Chimney for Stirling Motor	04372.04
Sensor Unit *pVn*	04371.00
pVnT Instrument	04371.97
Thermocouple, NiCr/Ni, sheathed	(2x) 13615.01
Oscilloscope, 20MHz, 2-channel	11454.93
Screened Lead, BNC	(2x) 07542.11
Rheostat, 330 Ω	06116.01
Connecting leads	

6 EXPERIMENTS

The supplementary devices which are matched to the Stirling motor enable a large variety of qualitative and quantitative experiments to be undertaken.
- Conversion: heat - mech. energy - light
- Operation as heat pump or refrigeration machine
- Mech. power in relation to speed (Fig. 3)
- Electr. power in relation to speed (Fig. 3)
- Temperature measurement
- Recording of the *pV* curve

7 BIBLIOGRAPHY:

University Practical Physics, Part 5, Experiment 3.19.

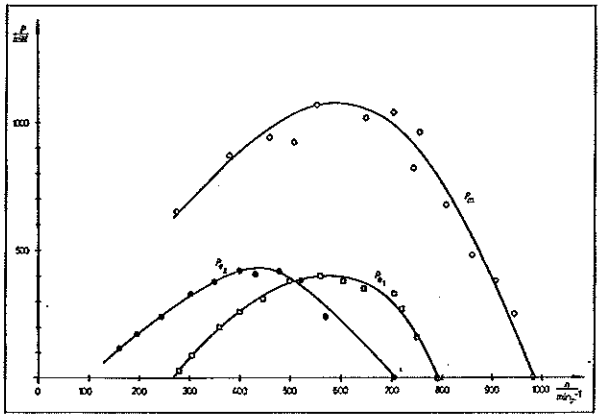


Fig. 3: Mechanical power P_m and electrical power P_e in relationship to the speed (P_{e1} = large pulley, P_{e2} = small pulley)

4 CALIBRATION OF TEMPERATURE AND VOLUME ON SWITCHING ON THE UNIT

The accuracy of NiCr/Ni thermocouples (0.1K) is good enough for relative measurements, but the absolute values of two probes can vary from one another by up to 6ÞC.
Therefore, a calibration procedure is necessary for the measurement of the difference T_1-T_2.
A calibration procedure is also necessary for the volume measurement:
The present air volume in the Stirling motor is found from the position of the main piston, i.e. from the angle of the crankshaft using the incremental transmitter. An initial value must be specified for this.

Temperature

The instrument always carries out a self-test of all components directly after being switched on. Once this test has been successfully completed the middle display requests „CAL".

- The two connected temperature probes must now be brought to the same temperature (e.g. water bath), then the button (6) „Calibrate ΔT" should be pressed.
- The instrument takes both measurements and stores the difference until it is switched off.

This calibration has no effect on the display of the absolute values.
If only one temperature probe is used or if the difference is not of interest, the button can be pressed at any probe temperature.

Volume

The label „ot" (oberer Totpunkt = top dead centre) appears on the upper display after the temperature calibration.

- The incremental transmitter on the sensor unit must now be firmly fastened to the Stirling motor crankshaft and the sensor unit must be connected to the 8-pole socket on the instrument.
- The main piston is then brought into the position at which the smallest volume is present in the Stirling motor, i.e. the main piston is located at its lowest point. The button (7) „Calibrate V") is pressed with the piston in this position.
- Incorrect calibration results in an offset in the volume computation and therefore to deformation of the pV curve.

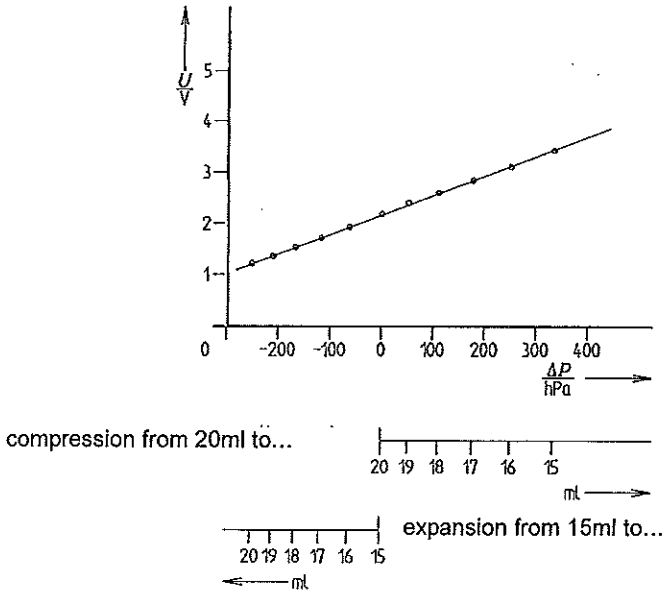
The buttons for the calibration procedures have no further function during the rest of the operation. A new calibration procedure can only be initiated by switching the instrument off and then on again.

5 CALIBRATION OF THE OUTPUT VOLTAGE FOR PRESSURE

The pressure sensor measures the pressure difference compared to the air pressure p_0. Its output voltage is amplified by the instrument and an offset voltage is set corresponding to the air pressure p_0. The gain and offset of the instrument are set to the typical characteristic data of the pressure sensor so that the Stirling measurement instrument is independent of any particular sensor unit.

Therefore, the pressure-output voltage of the instrument should be calibrated for the sensor/instrument combination that is being used for the evaluation of the pV curve. This can be easily carried out with the aid of a gas syringe:

The section of hose is removed from the hose connection on the mounting plate and the voltage for the air pressure p_0 is found.
The piston of a firmly closed gas syringe is, for example, withdrawn to 20ml and then connected to the sensor with a section of hose. The pressure can be simply increased by pushing in the piston in ml steps, say up to the 15ml mark. This process is isothermal.
The sub-pressure range is then measured by an appropriate expansion, say in steps from 15ml to 20ml. The volume of the section of hose, which is about 0.07ml, can be neglected. The illustration shows a measurement example.



Calibration of the output voltage for pressure (measurement example), voltage U as function of the gauge pressure $\Delta p = p - p_0$.

6 TECHNICAL DATA

Pressure

The pressure sensor output voltages are further amplified by the instrument.

Pressure sensor data (for 5V operating voltage):

Sensitivity	typ. $44 \cdot 10^{-6}$V/hPa
	(min. $28 \cdot 10^{-6}$V/hPa)
Linearity	typ. 0.15% (max. 0.35%)
Voltage at p0	typ. 0mV (+/-25mV)
Instrument data:	
Gain	114
Output voltage:	typ. $5.0 \cdot 10^{-3}$V/hPa
	(min. $3 \cdot 10^{-3}$V/hPa)
At p0	typ. 2.5V (+/-2.8V)

Speed and volume

The voltage value for the volume is computed from the position of the incremental transmitter. To do this, the smallest volume V_{min} is assigned the value 0V in the calibration procedure.

Incremental transmitter:	256 pulses/turn
Speed display:	max. 1999 rpm
Output voltage	4.2V/cm^3
At volume	V_{min} (32cm^3) = 0.0V
	V_{max} (44cm^3) = 5.0V

Temperature

On the hot side of the Stirling motor a temperature measurement of at the most 1°C accuracy is practicable in motor mode due to the temperature gradients that exist on this side (flame). The position of the measuring point has been selected, according to thermographical image recording, where an average temperature on the gradient is produced. In the thermal pump mode of operation or as a refrigeration device, the temperature changes of the system are substantially lower. Therefore, a resolution of 0.1°C has been selected for the second temperature measurement point.

T_1 and ΔT:	
Measurement range:	–10°C ...+400°C
Resolution:	1°C
T_2:	
Measurement range:	–10.0°C ...+99.9°C
Resolution:	0.1°C

7 LIST OF EQUIPMENT

(for test arrangement)

Stirling Motor Instrument, *pVnT*		04371.97
Sensor Unit *pVn*		04371.00
Stirling Motor, transparent		04372.00
Motor/Generator Unit		04372.01
Torque Meter		04372.02
Chimney for Stirling Motor		04372.04
Thermocouple, NiCr/Ni, sheathed	(2x)	13615.01
Oscilloscope, 20MHz, 2-channel		11454.93
Screened Lead, BNC, 500mm		07542.11
Gas Syringe, LUER, 20ml, 1 pce.		02591.03

A computer interface with an xy tracing program can be used to record the *pV* curve instead of an oscilloscope.

8 BIBLIOGRAPHY

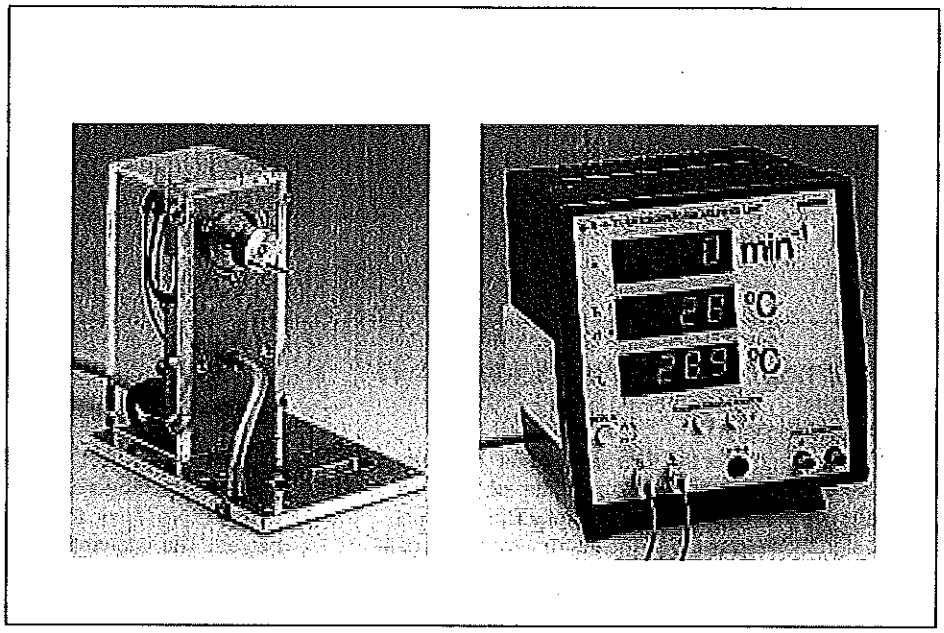
University Practical Physics, Part 5; Experiment 3.19.

PHYWE

Sensor Unit *pVn*
Stirling Motor Instrument, *pVnT*

04371.00
04371.97

Operating Instructions



04371.00 04371.93

1. PURPOSE AND CHARACTERISTIC PROPERTIES

The sensor unit and instrument have been specially developed for the transparent Stirling Motor 04372.00. They are used for the measurement and display of all thermodynamic variable quantities associated with the Stirling motor.

Pressure
A sensitive, temperature compensated sensor continually measures the pressure in the Stirling motor.
Output: analogue voltage value.

Volume and speed
The motion of the main piston monitored by an incremental transmitter linked to the crankshaft. This enables the rotational speed and the present air volume in the Stirling motor to be computed.
Speed output: 4-figure digital display.
Volume output: Analogue voltage value.
A *pV* curve can be displayed using, for example, an oscilloscope.

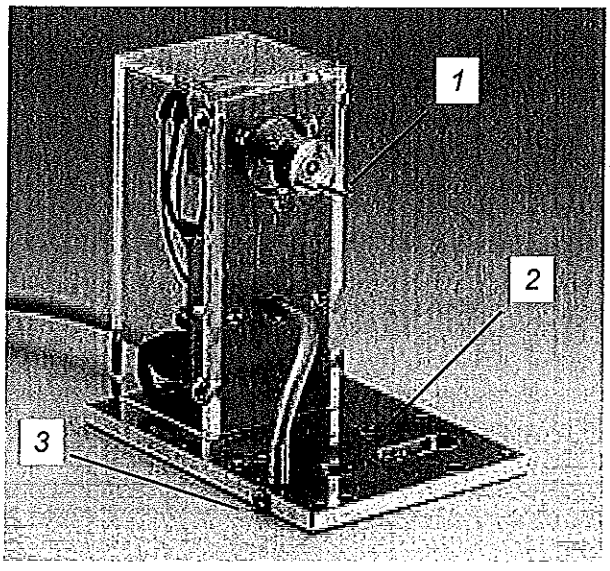
Temperature
The temperature in the cold and hot parts of the displacement cylinder is measured with NiCr/Ni thermocouples through two measurement connections.
Output: Two 4-figure digital displays.
Display T_1 can be switched to differential measurement $T_1 - T_2$.

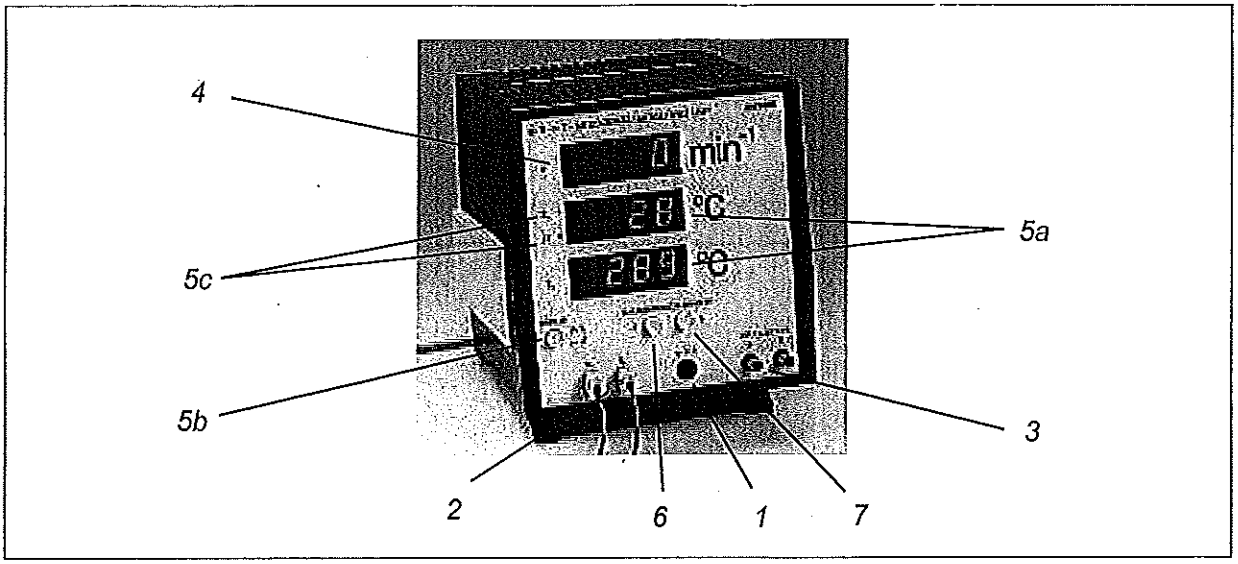
2 MOUNTING THE *pVn* SENSOR UNIT

The sensor unit and the Stirling motor must be firmly joined for the measurement of pressure, volume and speed. A dog is attached to the shaft of the incremental transmitter (*1*). It can be loosened and tightened using an Allen key supplied with the Stirling motor. This dog should be pushed up fully against the measurement tower before assembly.

The Stirling motor is loosened from the blue base plate. Then the mounting plate at the bottom is removed with a screwdriver. The Stirling motor is then fastened to the mounting plate on the sensor unit (*2*).

The dog on the incremental transmitter is pushed towards the Stirling motor, coupled to the mushroom shaped flywheel mass and tightened to the shaft. Finally, the Stirling motor is again screwed with the sensor tower to the blue base plate.
The pressure sensor must be joined to the hose connection on the mounting plate using a thick-walled piece of hose.





3 DESCRIPTION OF THE *pVnT* MEASUREMENT INSTRUMENT

1 *8-pole DIN socket*
For the connection of the *pVn* sensor unit. The pressure sensor and incremental transmitter obtain their power supply through this connection. The measurement signals are passed to the instrument for processing and display.

2 *Inputs*
For NiCr/Ni thermocouples (Order no. 13615.01)

3 *Analogue outputs*
For pressure and volume for the display of the *pV* curve, for example, using an oscilloscope or a computer interface.

4 *Digital display*
For the speed.

5 *Digital displays*
For the temperatures (5a). In the middle display the temperature T_1 or the difference T_1 - T_2 can be displayed. The latchable button „Display" (*5b*) is used to select the display. Two light emitting diodes (*5c*) indicate which of the two quantities is being displayed.

6 *Button*
For balancing the two temperature probes (see Sect. 4 „Calibration on switching on the unit").

7 *Button*
For confirming the position of the main piston for the computation of the volume (see Sect. 4 „Calibration on switching on the unit").

Experimental arrangement