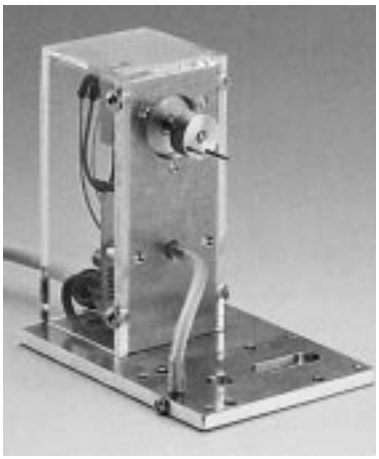
Sensor Unit *pVn*
Stirling Motor Instrument, *pVnT*

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

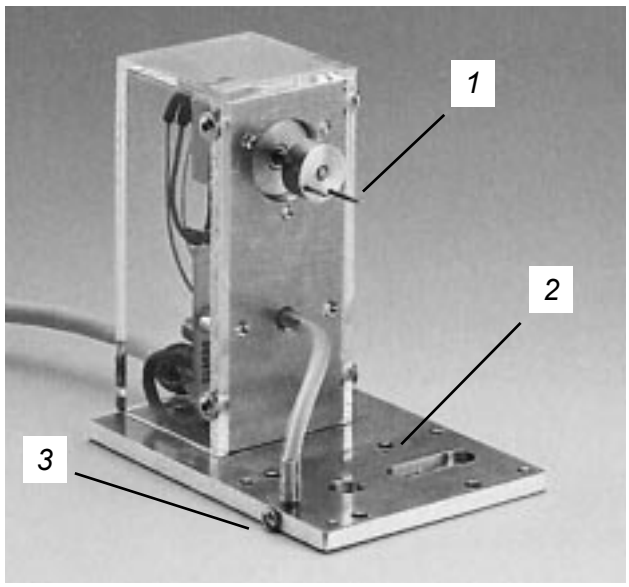
The temperature in the cold and hot parts of the displacement cylinder is measured with NiCr/Ni thermocouples through two measurement connections.
Output: Two 4-figure digital displays.
Display T_1 can be switched to differential measurement T_1 - T_2.

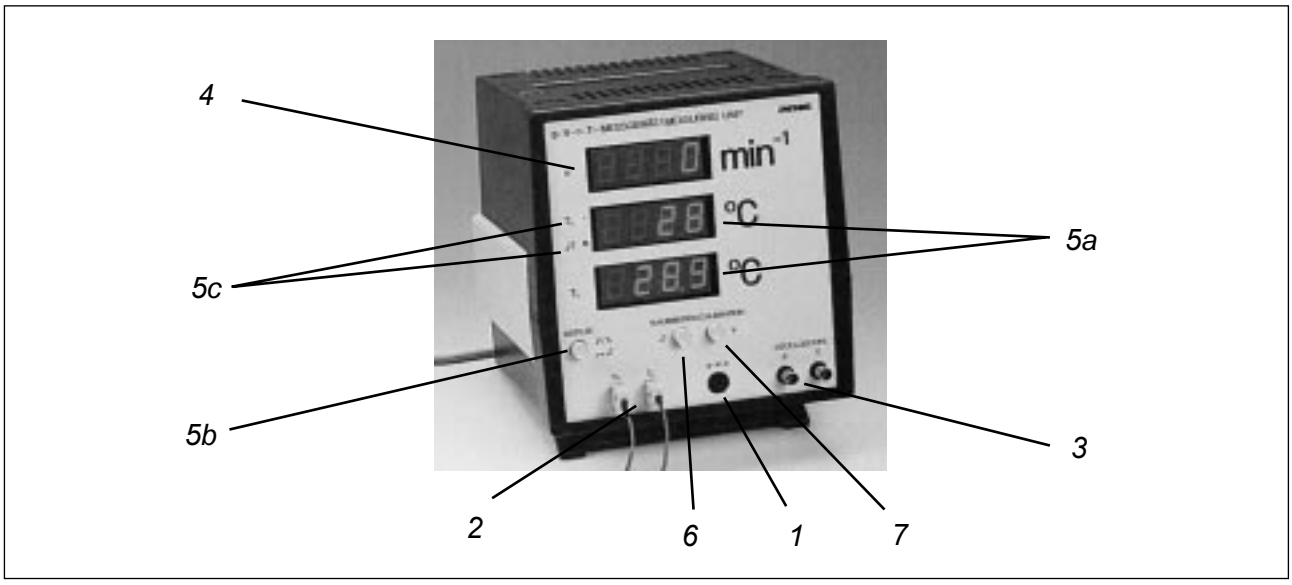
2 MOUNTING THE *pVn* SENSOR UNIT

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.

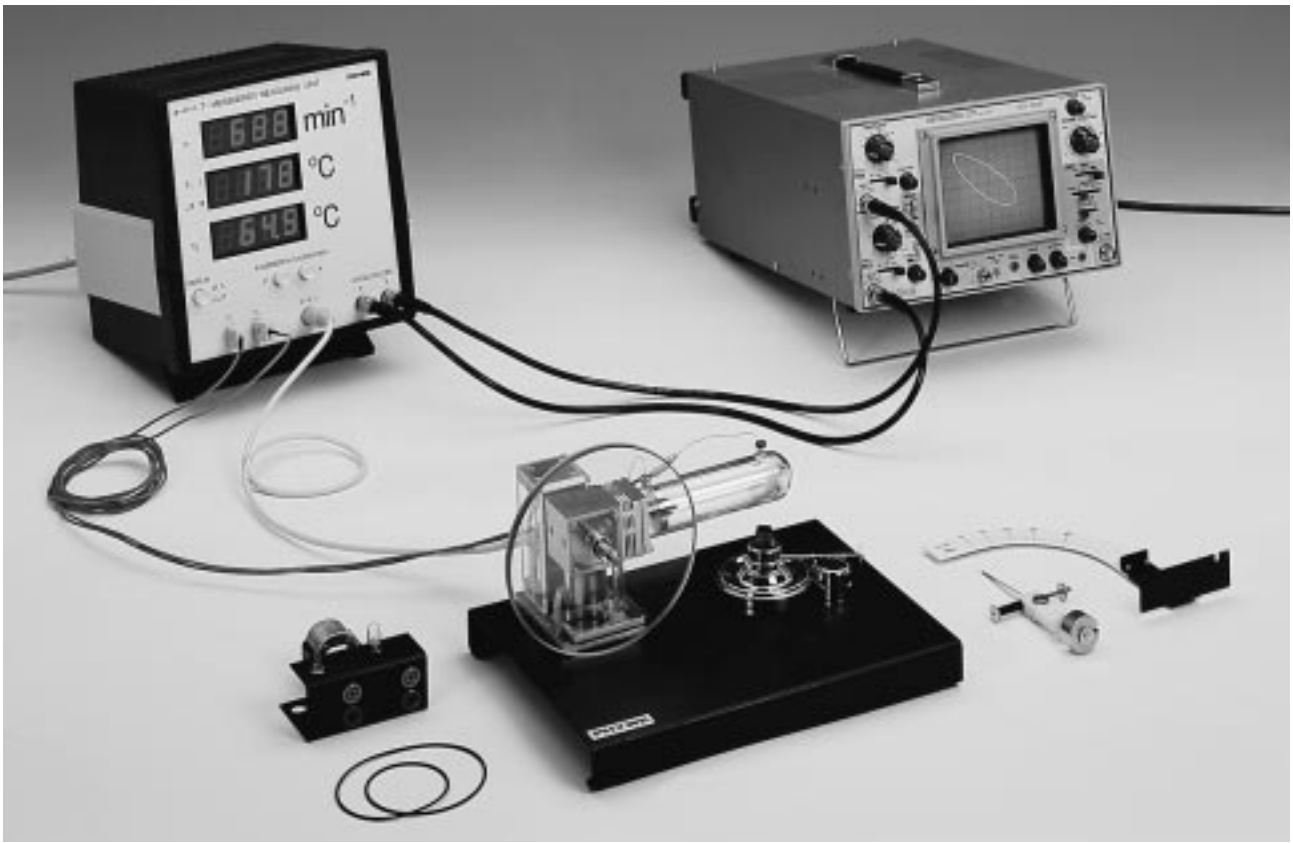
4 Digital display
For the speed.

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



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“ (**o**berer **T**otpunkt = 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.

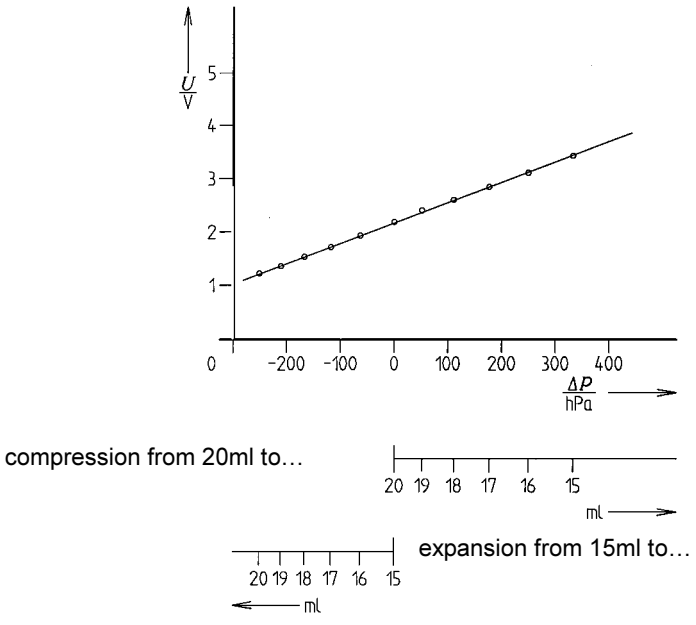
The buttons for the calibration procedures have no further function during the rest of the operation. A new calibration procedure can only be initiated by switching the instrument off and then on again.

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.