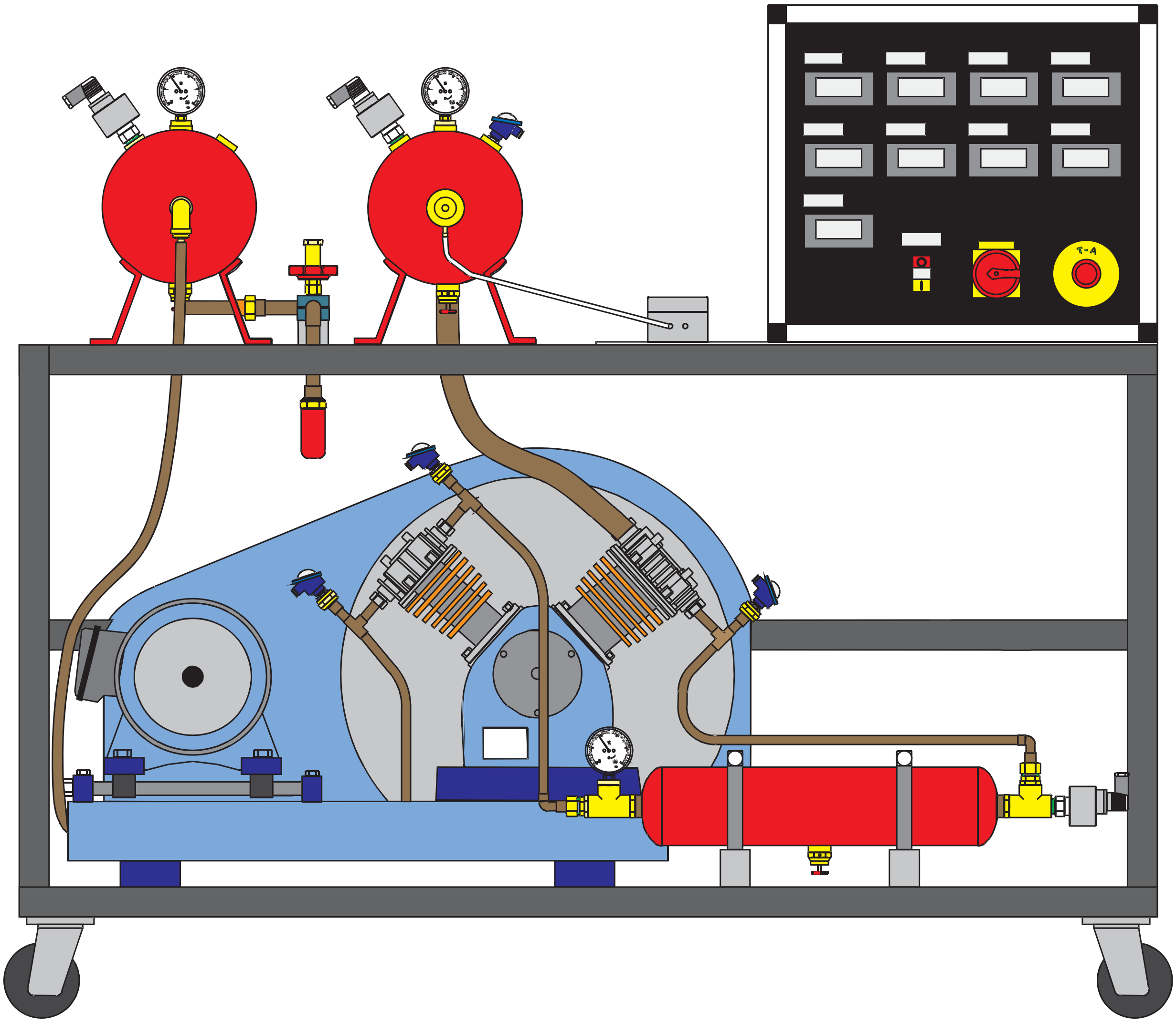
Instruction Manual

ET 500 Two-Stage Piston Compressor

ET 500 TWO-STAGE PISTON COMPRESSOR



Instruction Manual

Please read and follow the safety regulations before the first installation!

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1 Introduction

1.1 Usage of the Compressor

The compressor is part of an air compressor unit. Such units are used where compressed air is used as a source of energy. Especially in places of work where there is a risk of explosion due to flammable gases, e.g., in mining or in the chemical industry, compressed air is used instead of electrical energy.

- Mining: Machine drives
- Chemical industry: Regulation and control engineering
- Workshops, petrol stations: Tools, paint spraying, air for tyres
- Assembly shops: Automation, pneumatic controllers

An air compressor unit essentially comprises:

- Compressor (1)
- Drive motor (2)
- Compressed air tank (3)
- Safety valve (4)
- Pressure switch (el. drive) (5)
- Manometer (6)
- Lines (7)
- Chassis (8)

It can also include air coolers, pressure reducers, water separators etc.

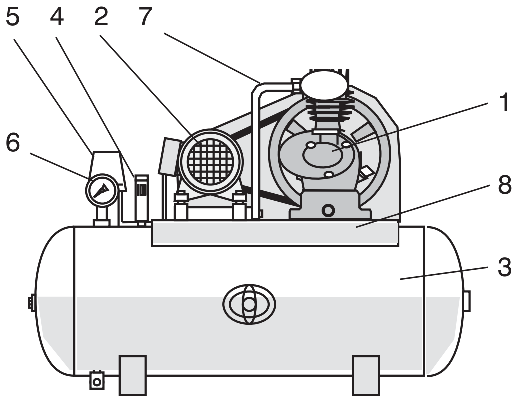


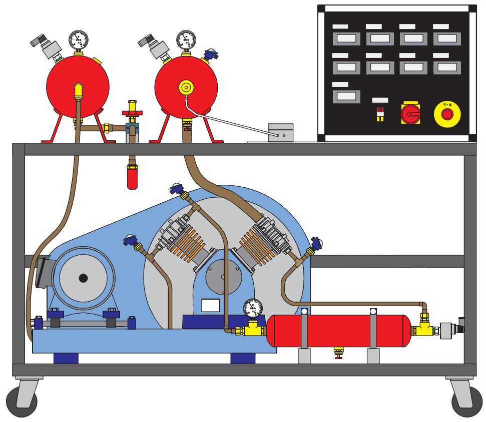
Fig. 1.1 Air compressor unit

The compressor is the central element in an air compressor unit.

Here the mechanical energy supplied is converted into an increase in the pressure of the air.

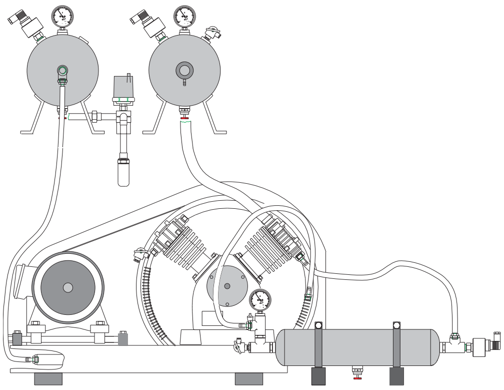
2 Description

2.1 Layout of the Test Stand



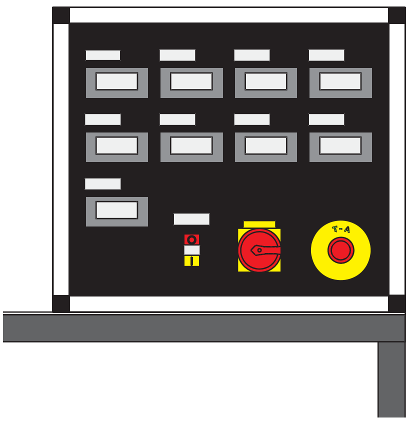
The entire test stand is mounted on a welded square steel tube support.

- Four castors for ease of movement and manoeuvring of the unit
- Two rollers with brakes for secure positioning
- Dimensions are such as to permit passage through normal doorways



The test stand has a complete air compressor unit with a 2-stage built-in compressor and compressed air tank.

- Only a power supply is needed to operate the system.
- Quiet experimental operation due to cushioned unit suspension
- All measuring transducers and fittings meet current industry standards
- Large intake damper to smooth the volume flow and as a support for measuring sensors



All electrical controls and displays are fitted in a switch cabinet.

- Master switch and emergency stop switch
- Digital displays for all measured values
- Switch for compressor

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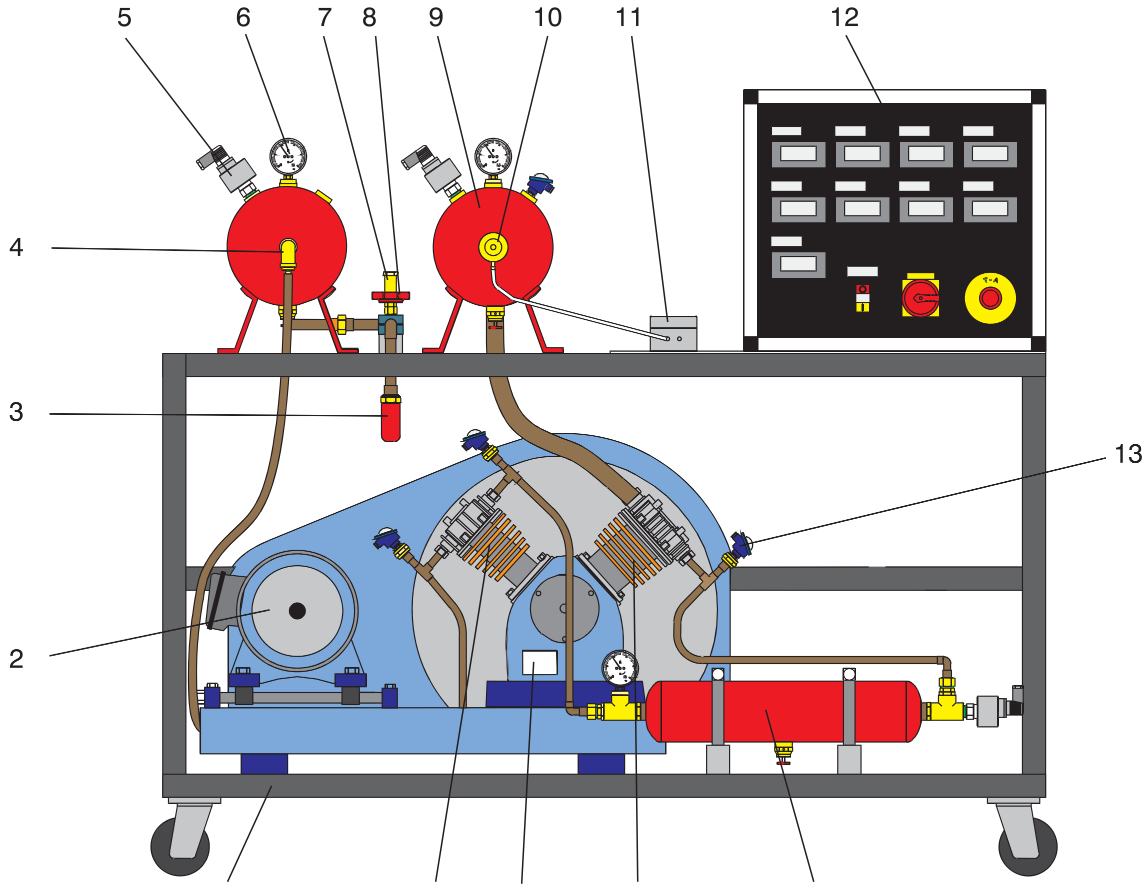


1 Trolley	10 Nozzle for volume flow measurement
2 Drive Motor	11 Differential pressure transducer
3 Acoustic attenuator	12 Switch Cabinet with Digital Displays
4 Pressure vessel 2nd stage	13 Resistance thermometer
5 Pressure transducer	14 Pressure vessel and intermediate cooler for 1st stage
6 Manometer	15 1. Compressor Stage
7 Safety valve	16 2-Stage piston compressor
8 Regulating valve	17 2. Compressor Stage
9 Inlet pressure vessel	

Fig. 2.1 Piston compressor test stand

2.2 Switch Cabinet Display Instruments

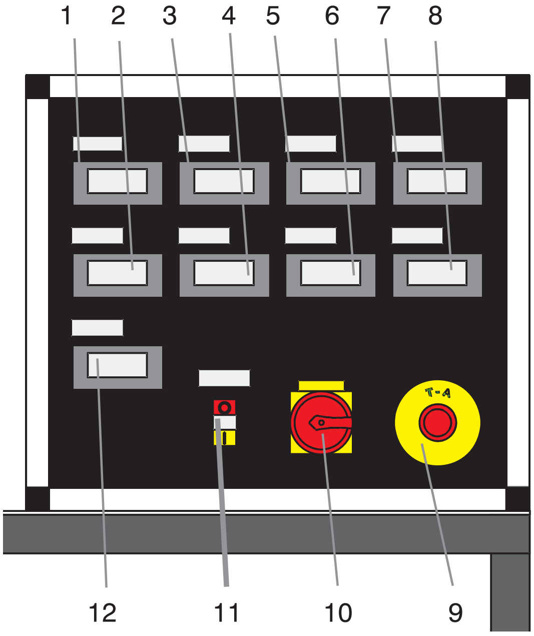


Fig. 2.2 Switch cabinet with displays and controls

1 p1-Inlet pressure
2 T1-Inlet temperature
3 p2-Pressure after 1st compressor stage
4 T2-Temperature after 1st compressor stage
5 p4-Pressure vessel pressure
6 T3-Temperature before 2nd compressor stage
7 dp-Differential pressure across Venturi nozzle
8 T4-Temperature after 2nd compressor stage
9 Emergency stop switch
10 Master switch
11 Electric motor switch
12 Electrical output

2.3 Process Description

The ET500 piston compressor test stand operates as a two-stage compressor station. The air is drawn into the tank (1) via a measuring nozzle. Tank 1 acts as a calming zone and as a housing for the measuring sensors for the intake state. The measuring nozzle is used to determine the intake volume. Between the 1st and 2nd stage, there is a small pressure vessel for intermediate cooling. After the 2nd stage, the compressed air is forced into tank 2, the compressed air tank, via a cooling tube.

To achieve a steady operating state, the compressed air can be blown off via a bleeder valve with sound absorber.

Safety valves and pressure switches complete the unit.

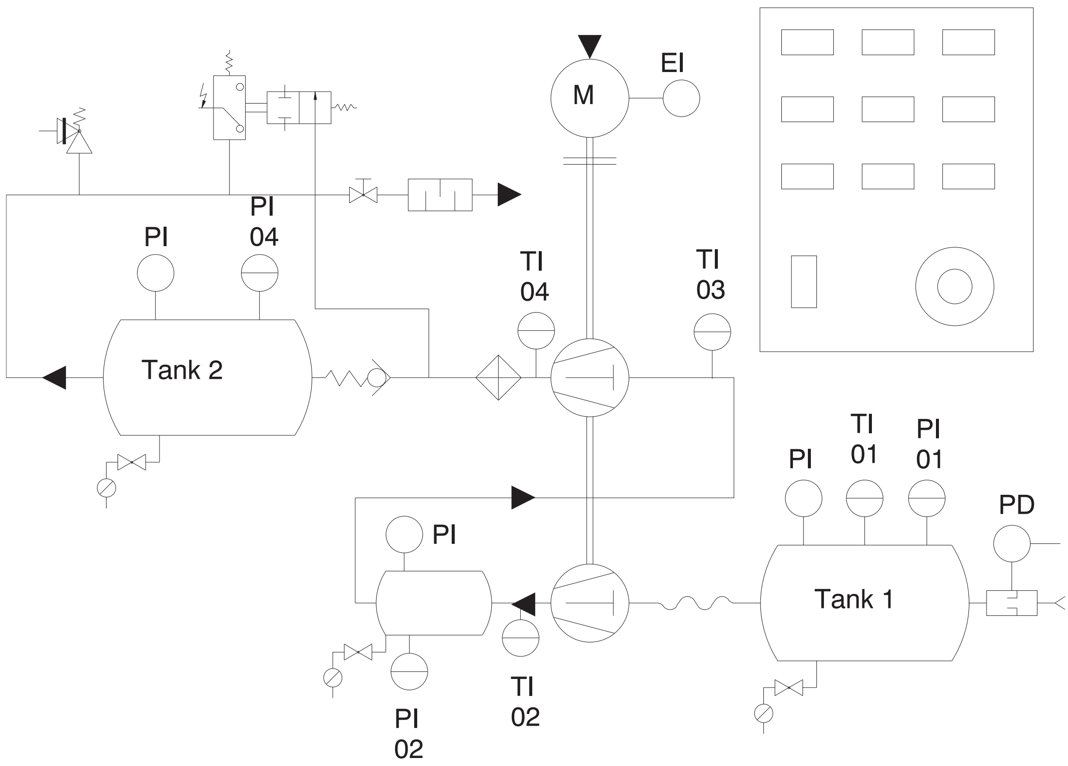


Fig. 2.3 Process diagram

2.4 Commissioning

- Place the test stand on a level surface and secure against rolling away by locking the brakes.
- Connect to power supply
- Carry out oil check with motor OFF (see also Maintenance)
- Switch on the system by pulling the emergency off button and turning the master switch **ON**
- Switch on the compressor by turning the button on the switch cabinet **ON** and turning button I on the pressure switch **ON** (between the two upper pressure tanks). Compressor should cut out with closed bleeder valve at approx. 12 bar and cut-in at approx. 10 bar. The cut-in and cut-out pressure can be adjusted on the pressure switch.

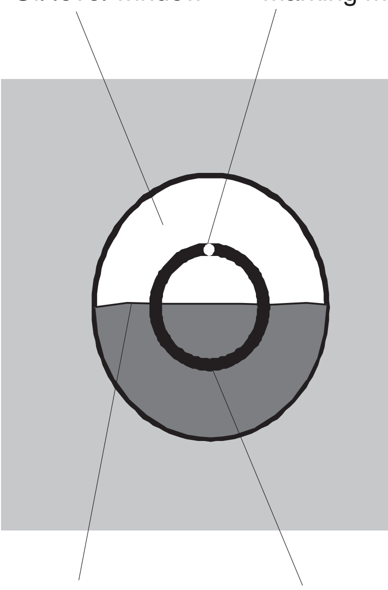
2.5 Shutting Down

- **Always press button 0 on the pressure switch first, so that the ventilating valve is activated.** The ventilation valve ventilates the line to the compressor, making it easier for the motor to start up.
- Switch the compressor **OFF** using button (11) on the switch cabinet
- Switch off the master switch (10)

2.6 Maintenance/Care

The maintenance of the unit is limited to the maintenance of the built-in compressor. The operating instructions for the compressor from KAESER are to be followed for maintenance.

The tasks described here are, as a rule, only necessary on compressors operated as intended. During laboratory use, the compressor is only operated occasionally, such that maintenance is limited to filling with oil and checking the oil level.



Oil Level and Oil Change

Oil level:

Prior to commissioning, check and if necessary fill the compressor with oil.

– Check oil level using the marking in the oil level window, if the level is below the minimum, top up with oil using the oil filler up to the max. oil level.

Oil change:

Change the oil while the unit is warm.

– Drain oil by removing the oil drain plug

– Only use the stipulated engine oil for flushing the crankcase

– Top up the oil as far as the mark using the oil filler.

CAUTION! Close oil drain plug first! For maintenance intervals and oil specification, see Section 6.2 Technical data

2.7 Software

2.7.1 Installation of the Software

The following is needed for the installation:

- A fully operational PC with USB port (for minimum requirements see Chapter 6.2).
- G.U.N.T. CD-ROM

  All components necessary to install and run the program are contained on the CD-ROM delivered by G.U.N.T.

Installation Routine

Notice:
The test stand must not be connected to the PC's USB port during the installation of the program. Only after the software has been installed can the trainer be connected.

- Boot the PC.
- Load the G.U.N.T. CD-ROM.
- From the "Installer" folder, launch the "**Setup.exe**" installation program.
- Follow the installation procedure onscreen.
- After starting, the installation runs automatically. During the course of the installation, various program components are loaded onto the PC:
  - Program for PC-data acquisition
  - Driver routines for the "LabJack®" USB converter
- Reboot the PC after installation is finished.

2.7.2 Operating the Program

Fig. 2.4 Language selection

- Select and start the program by choosing: **Start** / **All Programs** / **G.U.N.T.** / **ET500**.
- When the software is run for the first time after installation, the language to be used for the program is requested.

  The languange selected can subsequently be changed at any time on the "**Language**" menu.
- Various pull-down menus are provided for additional functions.
- For detailed instrauctions on use of the program refer to its Help functin. This **Help function** is accessed by opening the pull-down menu "**?**" and choosing "**Help**".

Stored measurement data can be imported into a spreadsheet program (e.g. Microsoft Excel) for further processing.

3 Safety

The experimental instructions, in particular the safety instructions, are to be read through carefully prior to commissioning.

Participants in the experiment are to be instructed on the correct operation of the unit priorto the experiment.

It is imperative that the following safety instructions are observed for hazard-free and correct operation.

3.1 Health Hazards

DANGER!

Caution when making changes to electrical system components. There is a risk of electric shock. It is therefore imperative to unplug the unit from the mains first. Only have work performed by suitably qualified personnel.

DANGER!

Caution near hot surfaces and system components. There is a risk of burns. Prior to working on system, leave to cool down.

DANGER!

Caution on the drive. There is a risk of injury due to rotating parts. Always operate the unit with a basket guard.

3.2 Hazards for Equipment and Function

ATTENTION!

The system must not be operated unsupervised.

CAUTION!

Do not modify or disable the safety devices fitted. Do not tamper with the safety valves.

Do not make modifications to the over-current protection switch!

CAUTION!

On the flow meter, exceeding the measuring range by more than 20% can impair the function. Pressure peaks and sudden inflow caused by solenoid valves, ball-cocks, or similar can result in irreparable damage to the unit.

4 Theory

4.1 Function

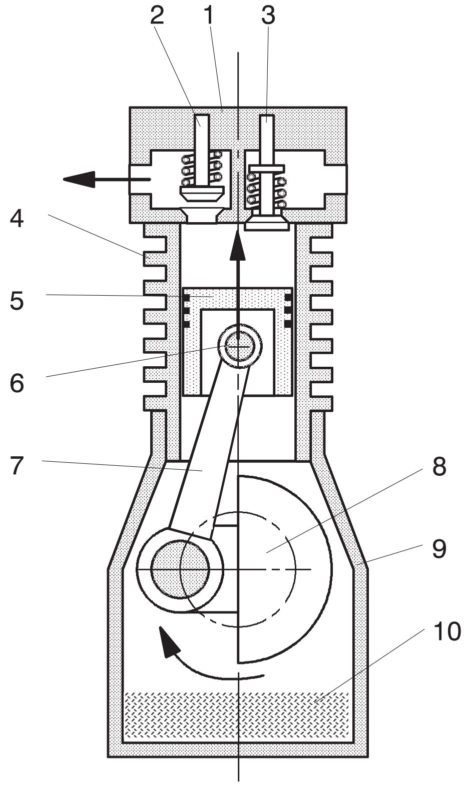


Fig. 4.1 Piston compressor

1 Cylinder cover
2 Pressure valve
3 Intake valve
4 Cylinder
5 Piston
6 Piston pin
7 Connecting rod
8 Crankshaft
9 Crankcase
10 Oil sump

Compressors are machines that pump gaseous media, in our case air, from areas of low pressure into areas of higher pressure. The energy supplied for this purpose by prime movers, such as electric motors or combustion engines, increases the pressure as intended, but also warms the air. The heat is, to some extent, dissipated to the ambient environment using cooling ribs.

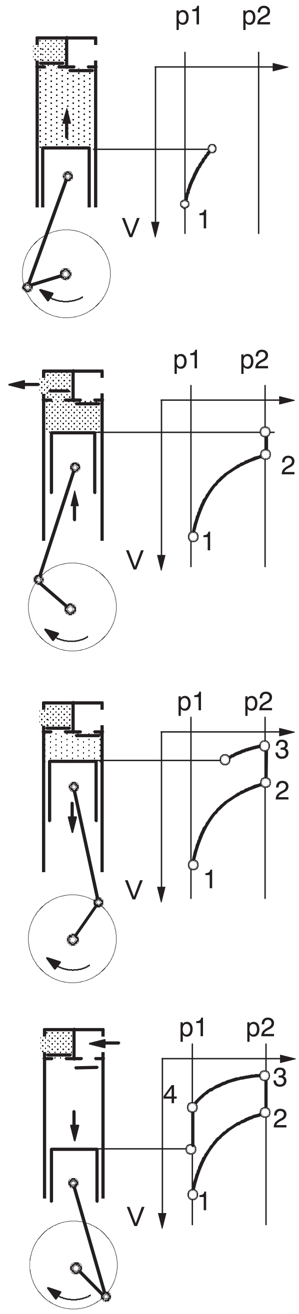
The figure shows the basic layout of a piston compressor.

The volume of air enclosed in the cylinder is compressed by the piston moving upward and pumped into the pressure line via a pressure valve.

On the downward movement, the piston draws in more air via the intake valve.

A crank drive, comprising a crankshaft and con-rod, generates the necessary upward and downward motion of the piston from an even rotary motion.

The lubricating oil necessary for lubrication of the moving parts collects in the oil sump.



The processes in the compressor can best be shown in a so-called **p,v diagram**.

In the p-v diagram, the pressure in the cylinder is plotted against the related cylinder volume. The figures below illustrate the individual phases of the compression. The p-v diagram is shown rotated by 90° to the right and thus corresponds to the piston stroke.

- **Compression**

  Starting from point 1, bottom dead centre (BDC), the piston compresses the air in the cylinder. With reducing volume, the pressure increases.

- **Expulsion**

  At point 2 the pressure in the cylinder has reached the pressure p2 in the pressure line. The pressure valve opens and the compressed air flows into the pressure line.

- **Return expansion**

  At point 3 the piston has reached top dead centre (TDC) and reverses its direction of movement. The pressure valve closes and the air remaining in the cylinder expands again. The pressure drops.

- **Intake**

At point 4 the pressure has dropped back to the ambient pressure p1 such that the intake valve opens and fresh air flows into the cylinder. This process continues until the piston has reached bottom dead centre (BDC). Here, at point 1 the entire process starts all over again.

– 2-Stage Compression

If the pressure ratio is increased during single stage compression, then the back-pressure and temperature of the medium increase. The pressure ratio during compression is limited by the temperature at which the lubricating oil - gas mixture can explode. On staged compression, the medium is cooled between the individual stages. In this way the volume losses, the rod forces and the drive power are reduced. The intermediate cooling effects a reduction in the intake pressure and the intake volume at the second stage. In the idealised p-v diagram, the process for the second stage after the intermediate cooling runs isentropically from 1II to the final pressure 2II. In the case of single stage compression, the process would run isentropically, without a jump, to the final pressure 2'. The difference between these two curves is the saving in work.

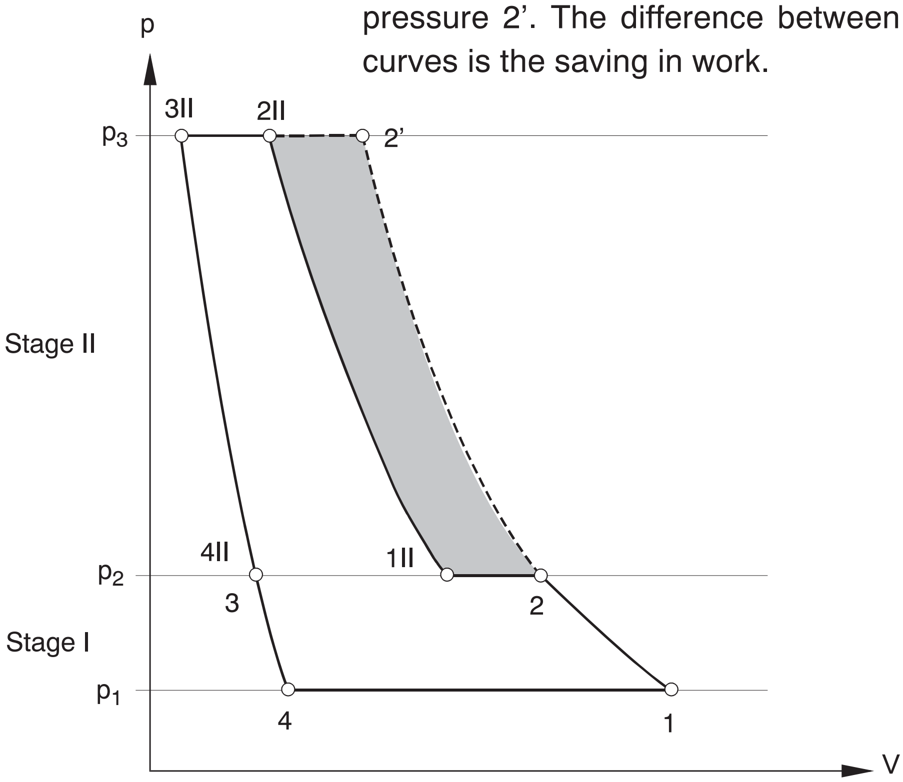


Fig. 4.2 Pressure progression on a p,v diagram

5 Experiments

5.1 Recording Measured Data with Different Back-pressures

5.2 Measured Data Recording

Pressure:

The digital displays indicate the absolute pressure at the measuring points in bar. The manometers on the tanks indicate the over-pressure at the measuring points in bar.

Differential pressure / Intake volume:

The differential pressure p in a Venturi nozzle is proportional to the flow rate

$$\dot{V} = A_d \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}}$$

with $\dot{V}$ in m³/s, Δp in Pa, ρ in kg/m3

and $A_d = 1.131 \cdot 10^{-4}\ m^2$

The density ρ of the air depends on the temperature and pressure

$$\rho = \frac{100 \cdot p_0}{287 \cdot (T + 273)}$$

with ρ in kg/m^3, p_0 in mbar and T in °C.

The differential pressure Δp in the system is formed from the ambient pressure and the pressure on the smallest cross-section of the Venturi nozzle. The measurement is output via the differential pressure transducer on the digital display in mbar.

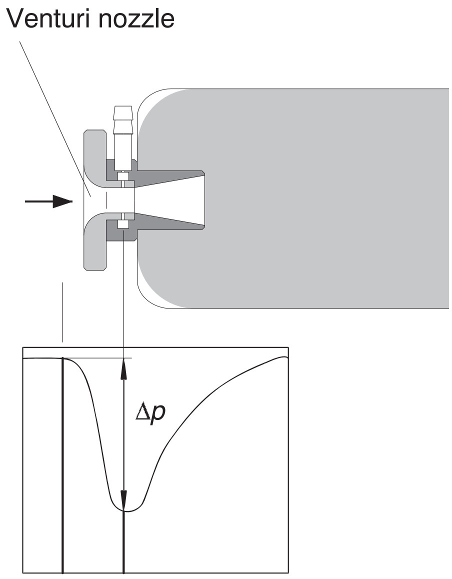


Fig. 5.1 Cross-section and pressure progression

Temperature:

Four resistance thermometers (Pt100) with transducers measure the temperature; this is indicated on the digital displays.

Rating:

The effective power of the compressor motor is measured using a transducer and indicated on digital displays.

5.3 Experimental Method

- **Switch on compressor** (see Section 2.4) If it does not start up, it is possible that the over-current protection switch may have cut out directly on the motor - restart.
- **Allow the system to run**, until a constant pressure p3 has built up, set the desired final pressure with the bleeder valve and record the measured values

5.4 Measured Values and Analysis

p_1 in bar	t_1 in °C	p_2 in bar	t_2 in °C	t_3 in °C	p_4 in bar	t_4 in °C	Δp in mbar	$\dot{V}$ in l/min	$P_{elec.}$ in Watt	Time [1] in min
0.99	23.0	3.4	127.1	58.8	11.7	151.6	7.4	239.51	2550	3
0.99	22.9	3.4	126.1	58.4	11.0	146.5	7.4	239.51	2510	3
0.99	22.8	3.3	125.1	58.0	10.0	141.5	7.5	241.12	2460	5
0.99	22.6	3.3	123.4	57.2	9.0	133.5	7.5	241.12	2400	5
0.99	22.3	3.2	121.0	56.1	8.2	124.2	7.6	242.73	2350	5
0.99	21.3	3.1	118.1	54.7	6.7	108.7	7.6	242.73	2240	5

1) Time until measured value stability

5.5 Calculation of the Efficiency

To determine the efficiency of the compressor, first the hydraulic power is calculated. The isothermic power for the compression with intermediate cooling is calculated as follows:

$$P_{hydr} = p_1 \cdot \dot{V}_1 \cdot \ln\left(\frac{p_4}{p_1}\right)$$

with p in Pa and $\dot{V}$ in m^3/s

The overall efficiency is the result of the relationship between the hydraulic output and the electrical power supplied.

$$\eta = \frac{P_{hydr}}{P_{elektr}}$$

6 Appendix

6.1 Working Sheets

p_1 in bar	t_1 in °C	p_2 in bar	t_2 in °C	t_3 in °C	p_4 in bar	t_4 in °C	Δp in mbar	$\dot{V}$ in L/min	P_{Wirk} in W	p_1 in bar

6.2 Technical Data

Overall Dimensions

Length		1520 mm
Width		800 mm
Height		1500 mm
Weight	approx.	260 kg

Power Supply 400 V / 50 Hz / 3

Alternatives optional, see rating plate

Compressor:

Manufacturer	Kaeser
Type	K 2502 H35

Cylinder		2 in V-shape
Max. pressure		35 bar
Working Pressure		12 bar
Intake Capacity		15 m^3/h = 250 l/min
Speed		710 min^{-1}
Stage 1		
	Bore	78 mm
	Length of driving rod	150 mm
Stage 2		
	Bore	45 mm
	Length of driving rod	150 mm
Stroke		72 mm

Maintenance intervals:

First oil change after 50 operating hours.

Further changes every 500 operating hours or annualy.

Oil specification:

HD motor oil to DIN 51 506

Viscosity class VG 30 to DIN 51 506

Oil quantity: approx. 1.5 l

Drive Motor:

Rating	2,2 kW
Speed	3000 rpm

Inlet Tank:

Volume	20 l
Max. pressure	16 bar

Intermediate Cooler Tank:

Volume	5 l
Max. pressure	16 bar

Outlet Pressure Vessel:

Volume	20 l
Max. pressure	16 bar

Differential Pressure Sensor:

Measuring range	0 - 10 mbar
Output signal	0 - 10 V DC
Supply	24 V DC

Pressure Sensor:

Measuring range	1x 0-1.6 bar abs.
	and 2x 0 - 16 bar abs.
Output signal	0 - 10 V DC
Supply	24 V DC

Resistance thermometer with transducer:

Type	PT 100
Measuring range	0 - 200 °C
Output signal	0 - 10 V DC

Power transducer:

Measuring range	0 - 2500 W
Output signal	0 - 10 V DC

Digital Displays with Transmitter Supply:

Display	3 1/2 digit
Transmitter Supply	24 V DC

Multifunction card with MAD 12a:

Analogue Inputs	16, 0-10 VDC
Digital inputs	16, TTL
Digital outputs	16, TTL

Data acquisition

Program environment:

LabVIEW Runtime

System requirements:

PC with processor Pentium IV, 1 GHz

Minimum 1024 MB RAM

Minimum 1 GB available memory on hard disk

1 CD-ROM drive

1 USB port

Graphics card resolution min. 1024 x 768 pixel, True Color

Windows XP / Windows Vista / Windows 7

6.3 Items Supplied

1 x ET 500 unit

1 x ET 500 Instruction manual