Experiment Instructions

HL 710 Air Duct Systems

Experiment Instructions

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This manual must be kept by the unit.

Before operating the unit:
- Read this manual.
- All participants must be instructed on handling of the unit and, where appropriate, on the necessary safety precautions.

Version 1.0

Table of Contents

1 Introduction

1.1 Purpose of the device, audience and learning objectives

The HL 710 air duct system has been designed for training in ventilation technology.

Various practical air duct systems can be built from the individual off-the-shelf components.

The action and behaviour of the system and its components is to be identified, measured and evaluated when operating the system with the fan.

For this purpose the delivery includes measuring devices in addition to the many components, such as a digital pressure gauge, an inclined tube manometer and an anemometer for measuring flow velocity.

Various pipes of the air duct system are fitted with pressure gauge adaptors. The fan's power consumption is indicated on the control cabinet by a voltmeter and an ammeter.

The components used here correspond to those used in air conditioning systems.

Learning objectives are

- Planning, designing and testing air duct systems
- Typical ventilation technology components
- Measuring the air flow and velocity
- Measuring dynamic and static pressures
- Determining pressure loss across various components such as bends, angles, distributors, etc.
- Recording system characteristic curves
- Recording the fan characteristic curve
- Determining the operating point
- Calculating the electric output of the fan motor with regard to current and voltage
- Calculating fan efficiency.

1.2 Didactic notes for teachers

This teaching material should be used to help you prepare your lesson. You can compose parts of the material as information for students and use it in class. In the teaching material you will also find prepared exercise sheets for the students along with the corresponding solutions.

We also provide you with these experiment instructions in pdf format on a CD to support learning. Within the context of your teaching duties, we grant you unlimited rights to reproduce the teaching materials.

We wish you much joy and success with the G.U.N.T. device HL 710 Air Duct Systems in your important task of introducing students and trainees to the fundamentals of technology.

Should you have any comments about this device, please do not hesitate to contact us.

2 Safety

2.1 Intended use

The unit is to be used only for teaching purposes.

2.2 Structure of safety instructions

The signal words DANGER, WARNING or CAUTION indicate the likelihood of occurrence and potential severity of injuries.

An additional symbol explains the type of danger or a command.

Signal word	Explanation
⚠ DANGER	Indicates a situation which, if not avoided, will lead to **death or** serious **injury**.
⚠ WARNING	Indicates a situation which, if not avoided, may lead to **death or** serious **injury**.
⚠ CAUTION	Indicates a situation which, if not avoided, may lead to **light or moderate** injury.
NOTICE	Indicates a situation which may lead to **device damage** or provides information on **operating the device**.

Symbol	Explanation
	Electric voltage
	Hazard area (general)
	Hand injuries
	Notice
	Wear ear defenders
	Wear gloves

2.3 Safety instructions

⚠ WARNING

When the control cabinet is open, electrical connections are exposed.

Risk of electrical shock.

- Before opening the control cabinet: Pull the plug out.
- All work must be performed by trained electricians only.
- Protect the control cabinet from moisture.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

2.4 Ambient conditions for the operating and storage location

- Free from dirt and humidity.
- Level and paved surface.
- Air at the operating and storage location and aspirated air:
  - Air temperature: +10 °C to +50 °C
  - Air quality: The air must not contain any corrosive, abrasive, adhesive, toxic, explosive or very moist substances.

3 Description of the system

3.1 System structure and components

3.1.1 Example structure

A variety of different air duct systems can be constructed using the individual components of the HL 710 system.

Fig. 3.1 shows an example structure.

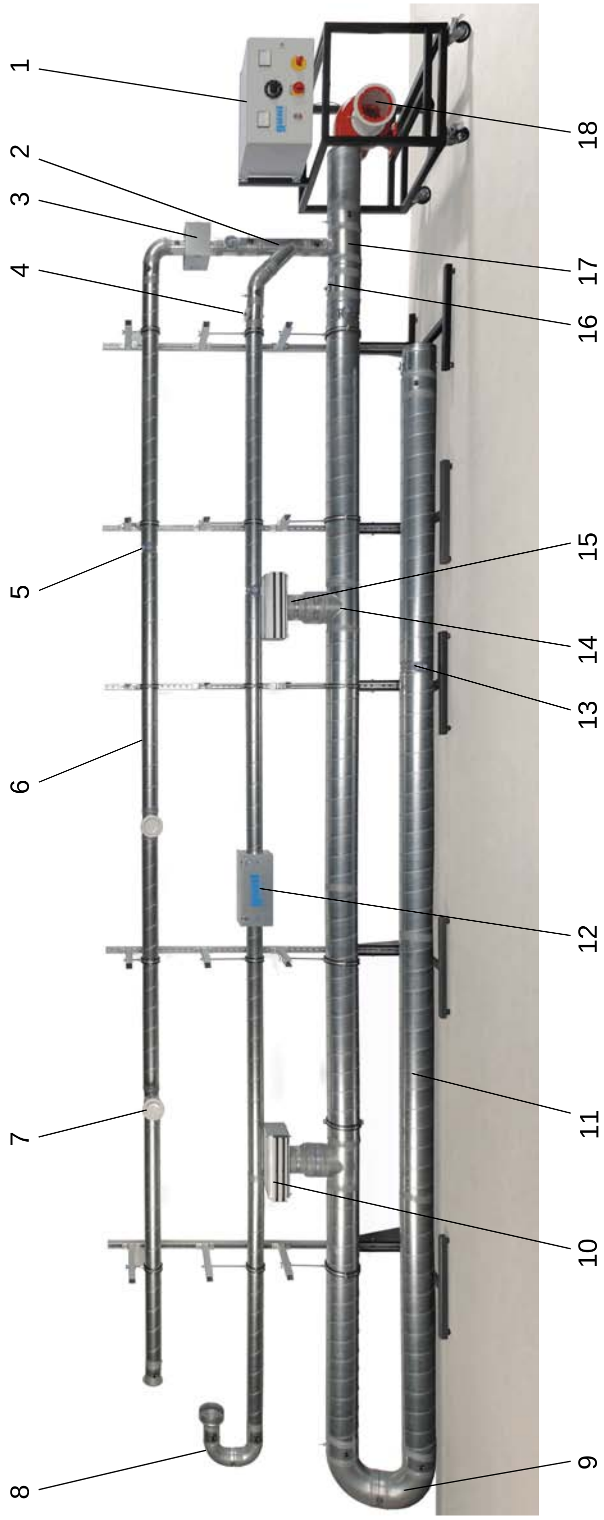


Fig. 3.1 Side view of the system

1	Control cabinet	10	Linear diffuser DN 160
2	45° branch DN 100	11	Pipe DN 200
3	Filter cartridge DN 100 for filter matting	12	Filter cartridge DN 100 for pocket filter
4	Throttle valve DN 100	13	Iris DN 200
5	Iris DN 100	14	90° branch DN 200
6	Pipe DN 100	15	Reducer DN 200 - DN 160
7	Outlet valve DN 100	16	Throttle valve DN 200
8	90° bend DN 100	17	90° branch with reducer DN 200 - DN 100
9	90° bend DN 200	18	Fan

3.1.2 Fan and control cabinet

Fig. 3.2 Fan and control cabinet

The air duct is operated by a portable fan, consisting of a movable frame, the fan, an electric motor and the control cabinet.

The fan inlet is protected by a coarse-meshed grille. The **fan** draws in air and then feeds it in a 90° bend via blades into the spiral housing and further into the pressure ports. A pipe is connected to the fan outlet.

The flow rate of the fan is varied with the rotation speed control knob, which is mounted on the **control cabinet**.

Details on the operation of the fan are contained in the manufacturer's instructions.

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120V: max 12,5A
  230V: max 6A

3.1.3 Assembly stand

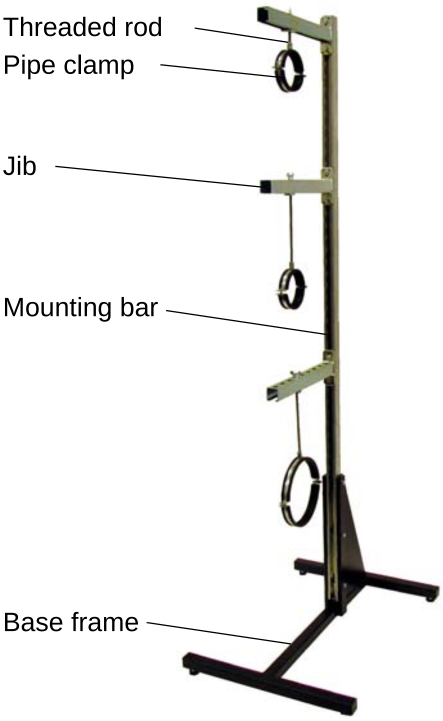


Fig. 3.3 Assembly stand

The air ducts are held by **assembly stands**. These can be positioned according to the structure of the air duct.

Each assembly stand consists of a stable base frame, on which a vertical mounting bar is screwed. Three height adjustable jibs are attached to the mounting bar.

The pipes are placed in rubber pipe clamps, which are screwed hanging onto the jibs using threaded rods.

The assembly stands can be connected and secured to each other with additional bars. Thus, stable air duct systems up to about 10 m long can be constructed.

3.1.4 Pipes and adapter pieces

Fig. 3.4 Spiral seam duct

The **pipes** are up to 1,6 m long spiral seam ducts with the nominal diameters DN 100 and DN 200. The outer spiral folded seam provides the rigidity required by the thin-walled pipes. The pipes are made of galvanized sheet metal.

Fig. 3.5 Plug connector

The pipes are connected together with **plug connectors.** A plug connector is plugged into the ends of the pipes to be connected, i.e. the plug connector sits inside. The joints are then sealed with adhesive tape.

Fig. 3.6 Sleeve

Sleeves are needed to connect different shaped pieces with each other. They are stuck on the ends of the respective elements to be connected, so that the sleeve is sitting on the outside.

Fig. 3.7 Reducer

Reducers connect pipes and other components of different nominal diameters.

3.1.5 Bends and branches

Fig. 3.8 90° bend and 45° bend

Installing **bends** makes it possible to change the direction within the air duct system.

Fig. 3.9 45° branch and 90° branch

Branched air duct systems can be built using **branches**.

45° branches are suited to the flow of air ducts. Just by looking it is obvious that the flow is better than in 90° branches.

Fig. 3.10 90° branch with reducer

A variant of the branch is the **branch with reducer.** This branches off from a large nominal diameter directly into a smaller nominal diameter.

3.1.6 Throttle valve and iris

The air flow can be throttled by flaps and apertures.

Fig. 3.11 Throttle valve

The **throttle valve** can be adjusted with a handle. Various lockable positions are possible, this means

- Position 0: Closed

  In this case, however, a small permeable annular gap remains between valve and pipe wall, so that the pipe is not blocked completely.

- Position 9: Open

Fig. 3.12 Iris with pressure measuring points

The **iris** can be moved into various positions using a knob that snaps into place, this means

- Position 1: Closed
- Position 6: Open

  The iris does not close completely. Approximately 34% of the pipe cross-section remains open.

Pressure measure points for static pressure are located directly in front of and behind the iris.

3.1.7 Pressure measuring points

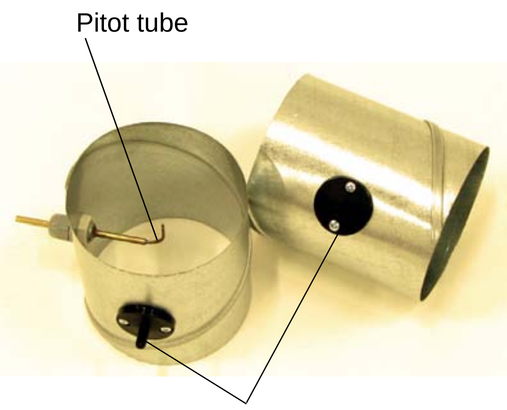


Fig. 3.13 Pressure measuring points

To take pressure measurements, a large number of short pipes with **pressure measurement points** are provided. They are designed so that they can be used in various parts of the air duct system.

The pressure measuring points consist of:

- a static probe to measure the static pressure
- or a pitot tube to measure the total pressure.

All pressure measuring points have a nozzle or a small tube, to which a PVC tube is connected, which connects the measuring point with the pressure gauge.

Depending on the arrangement of the pressure measuring points, pressure gradients are measured in the air duct system and pressure drops in individual components.

3.1.8 Filters and outlets

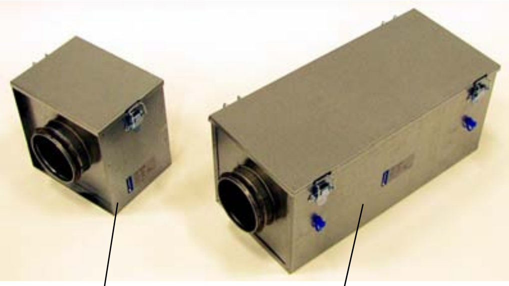


Fig. 3.14 Filter cartridges

Filters separate out liquid or solid particles from the air. The **filter elements** used here (filter matting and pocket filters) are used frequently in practice as pre-filters.

For training purposes, the **filter elements** of the HL 710 air duct system can be operated with and without filter elements.

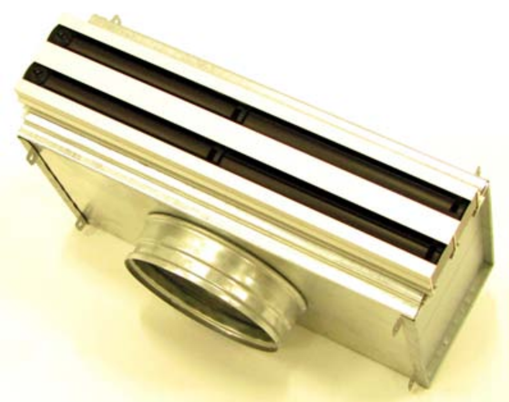


Fig. 3.15 Linear diffuser

Outlets distribute the air in the ventilated room.

Linear diffusers have shutters and valves to control the direction and intensity of the outgoing air flow. Here, the flow behaviour can be observed at different positions.

Linear diffusers should be adjusted in actual use so that people are not bothered by excessive draught.

Fig. 3.16 Outlet valve

The **outlet valves** used here are designed as disc valves. They are placed directly on a ventilation pipe.

- Fully open position:
  The plate is completely screwed out and removed. Air flows out vertically.
- Partially open position:
  The amount of air and the exit angle can be adjusted by turning the plate. Air is diverted sideways.
- Closed position:
  The plate is screwed in. However, a small annular gap remains, through which air flows out laterally. The outlet valve is therefore not blocked completely.

This type of outlet valve is primarily used as a ceiling outlet. Due to the air flowing out laterally, there is no noticeably excessive air velocity in the room.

3.1.9 Manometer

There should be at least 1m calmed distance before a pressure measuring point, in order to reduce measurement errors caused by turbulence.

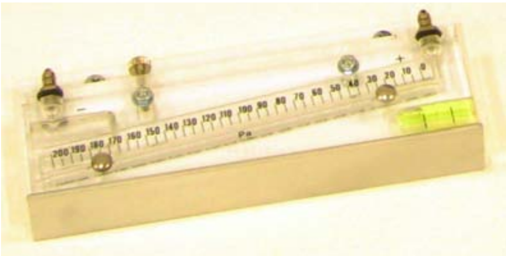


Fig. 3.17 Inclined tube manometer

Small pressure changes are measured with the **inclined tube manometer**.

Before using the inclined tube manometer, carry out the following steps in accordance with the manufacturer's instructions for the inclined tube manometer:

1. Align the inclined tube manometer horizontally.
2. Fill the inclined tube manometer with the manometer liquid.
3. Adjust the zero point.

Fig. 3.18 Digital manometer

The **digital manometer** is suitable for a large pressure range.

Details on operation are contained in the manufacturer's instructions for the digital manometer.

3.1.10 Anemometer

Fig. 3.19 Anemometer with volume flow hood

The **anemometer** is used to measure the flow velocity and the volume flow.

With the vane anemometer used here, there is a vane in the anemometer housing, which is set in rotation during inflow. The rotational speed is converted into flow velocity in the unit; this will then be shown on the display.

To measure volume flow rates, a volume flow hood is also used.

Details on operation are contained in the manufacturer's instructions for the anemometer.

3.2 Operation

3.2.1 Positioning and connection

1. Ensure that there is sufficient space available.

   The maximum length of the air duct system HL 710 is 11 m. Allow additional space for unrestricted inlet and outlet.

2. Lock the wheels of the frame on which the fan and the control cabinet are located.

3. Assemble the components to the desired experiment layout.

⚠ WARNING

Sharp edges on the pipes.

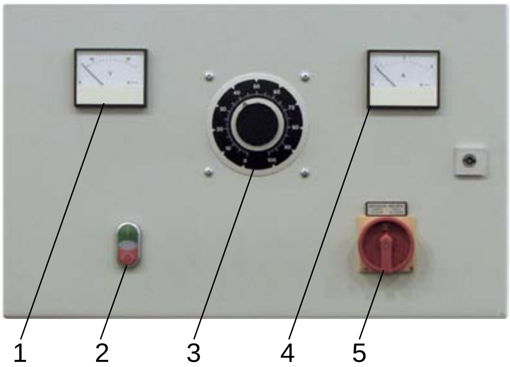
Risk of hand injuries.

- Wear gloves.

4. Seal the joints with adhesive tape.

5. Connect the control cabinet to the power supply.

3.2.2 Operation



1 Voltage display
2 Fan switch
3 Rotation speed control knob
4 Current display
5 Main switch

Fig. 3.20 Control cabinet

The **main switch** is used to turn the system on and off.

The fan is turned on and off with the **fan switch**.

The **voltage display** shows the voltage, the **current display** shows the electrical current.

The supply voltage and thus the speed of the fan is adjusted with the **rotation speed control knob**.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

3.2.3 Measuring pressures and differential pressures

Pressures and differential pressures at pressure measuring points can be measured both with the **inclined tube manometer** and with the **digital manometer**. Details on operation are contained in the respective manufacturer's instructions.

Fig. 3.21 Measuring the pressure relative to the atmospheric pressure

- Measure pressure relative to atmospheric pressure:
  - Connect the connector indicated with "**+**" on the pressure gauge with a hose to a **measurement point for static pressure**.
  - The connector on the manometer marked with "**-**" remains free.

Fig. 3.22 Measuring the differential pressure with the digital manometer

- Measure differential pressure:
  - Connect the connector indicated with "**+**" on the pressure gauge with a hose to the first **measurement point for static pressure**.

    The pressure at the first measuring point must be greater than the pressure at the second measuring point.
  - Connect the connector indicated with "**-**" on the pressure gauge with a hose to the second **measuring point for static pressure**.

Fig. 3.23 Measuring dynamic pressure with the digital manometer

- Measure dynamic pressure:
  - Connect the connector indicated with "**+**" on the pressure gauge with a hose to the **measuring point for total pressure**.
  - Connect the connector indicated with "**-**" on the pressure gauge with a hose to the **measuring point for static pressure**.

3.2.4 Measuring volume velocities and volume flows

Volume velocities and volume flows at pipe outlets are measured with the **anemometer**. Details on operation are contained in the manufacturer's instructions for the anemometer.

To measure volume flow rates, a volume flow hood is also used.

3.2.5 Maintenance

The HL 710 air duct system does not require maintenance.

See also the manufacturer's instructions of the components.

4 Basic principles

The basic principles set out in the following make no claim to completeness. For further theoretical explanations, refer to the specialist literature.

Knowledge of ventilation technology is a prerequisite for the experiments with the HL 710 air duct system, see also G.U.N.T. document "Fundamental Principles of Air Conditioning Technology".

4.1 Pressure, flow velocity and volume flow

The **total pressure** p_{total} in a pipe consists of

- the static pressure p_{stat}, that corresponds to the air pressure in the pipe, and
- the dynamic pressure p_{dyn}, which is generated by the flowing air.

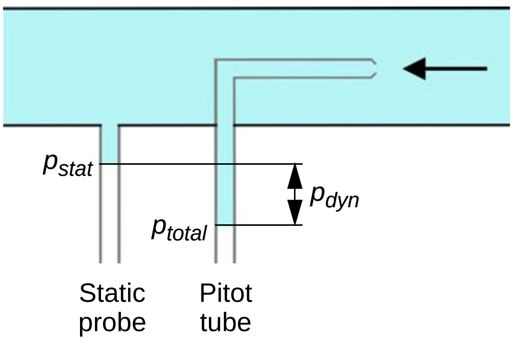


Fig. 4.1 Measuring the total pressure and static pressure

The total pressure p_{total} is measured with a pitot tube. It is located in the middle of the pipe and has an opening at the stagnation point.

The **static pressure** p_{stat} is measured at an opening with a static probe on the pipe wall.

The **dynamic pressure** can be calculated from the total pressure and the static pressure:

$$p_{dyn} = p_{total} - p_{stat} \quad (4.1)$$

The **flow velocity** can be calculated from the dynamic pressure:

$$v = \sqrt{\frac{2 \cdot p_{dyn}}{\rho}} \tag{4.2}$$

v	Flow velocity
ρ	Density of the flow medium Air: 1,225 kg/m^3 at 15 °C

The **volume flow** is determined from cross-section area and flow velocity.

The volume flow within an air duct system is almost constant. In pipes with a small cross-section, the flow velocity and thus the dynamic pressure are greater, in pipes with a larger cross-section the flow velocity and the dynamic pressure are less.

$$\dot{V} = A_D \cdot v = \text{constant} \tag{4.3}$$

$\dot{V}$	Volume flow
A_D	Cross-section area of the pipe

From Formula (4.2) and Formula (4.3) it thus follows:

$$\dot{V} = A_D \cdot \sqrt{\frac{2 \cdot p_{dyn}}{\rho}} \tag{4.4}$$

4.2 Pressure losses in pipes

Pressure losses arise in each pipe due to friction between the wall of the pipe and the flowing medium. Pressure losses due to friction are expressed by the pipe friction factor λ .

Pressure losses are calculated according to Formula (4.5).

$$\Delta p = \frac{\lambda \cdot l}{2 \cdot d} \cdot \rho \cdot v^2 \qquad (4.5)$$

Δp	Differential pressure
λ	Pipe friction factor
l	Length of the pipe
d	Diameter of the pipe

The formula can be solved for the pipe friction factor:

$$\lambda = \frac{2 \cdot \Delta p \cdot d}{\rho \cdot l \cdot v^2} \qquad (4.6)$$

4.3 Pressure losses in piping elements

Pressure losses occur in piping elements such as bends, branches and valves, as the pipe elements constitute obstacles to consistent pipe flow. They lead to turbulence and thus uneven flow through pipe cross sections.

The flow resistance R of the pipe elements is expressed by the dimensionless resistance coefficient ζ.

Pressure losses are calculated as follows.

$$\Delta p = \zeta \cdot \rho \cdot \frac{v^2}{2} \tag{4.7}$$

ζ Resistance coefficient

Correspondingly, the resistance coefficient can be determined according to Formula (4.8):

$$\zeta = \frac{2 \cdot \Delta p}{\rho \cdot v^2} \tag{4.8}$$

4.4 Characteristic curves

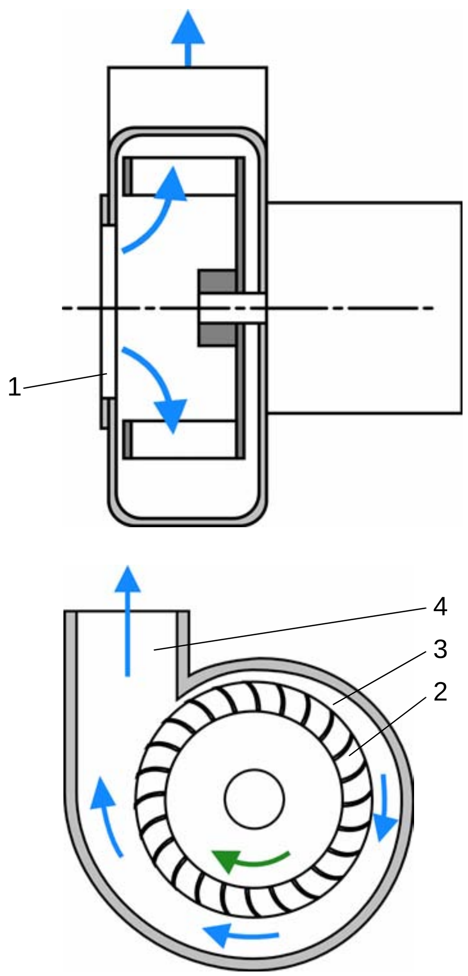
4.4.1 Functionality of a radial fan

An air particle passes through the air inlet (1) in the centre of the impeller (2). Kinetic energy is given to the particle by it being entrained by the impeller. Due to the centrifugal forces generated by the circular motion, the particle leaves the impeller and enters the spiral housing (3).

In the spiral housing, on the way to the air outlet (4), the particle is forced through the shape of the housing. In this way the particle becomes slower as the flow cross-section increases.

According to the law of continuity, therefore, the speed decreases. According to the law of conservation of energy decreasing kinetic energy leads to the increase in pressure energy.

The static pressure of the flowing medium is greatest at the end of the spiral housing. It establishes a steady state within the fan, with the higher pressure at the outlet and the lower pressure at the inlet. This ensures the free inflow of air from the atmospheric environment.



1	Air inlet
2	Impeller
3	Spiral housing
4	Air outlet

Air flow

Direction of rotation of the impeller

Fig. 4.2 Air flow in a radial fan

4.4.2 Fan characteristic curve

For a fan driven at a constant speed, the differential pressure depends on the volume flow. This relationship is shown in characteristic curves. Fan characteristic curves are like the fan's "fingerprint" and are therefore an important tool for designing a system.

Fan characteristic curves show the volume flows at different differential pressures. Each differential pressure value refers to a certain volume flow (see Fig. 4.3).

When recording a fan's characteristic curve, the fan's speed of rotation is not changed. The volume flow is varied by changing the flow resistance *R* and thus the resistance coefficient ζ, e.g. by using a throttle valve.

The fan characteristic curve for HL 710 is shown in Chapter 7.2, Page 175.

Altering the **speed** (see Fig. 4.3) alters the curve. Higher speeds cause greater differential pressures compared to low speeds.

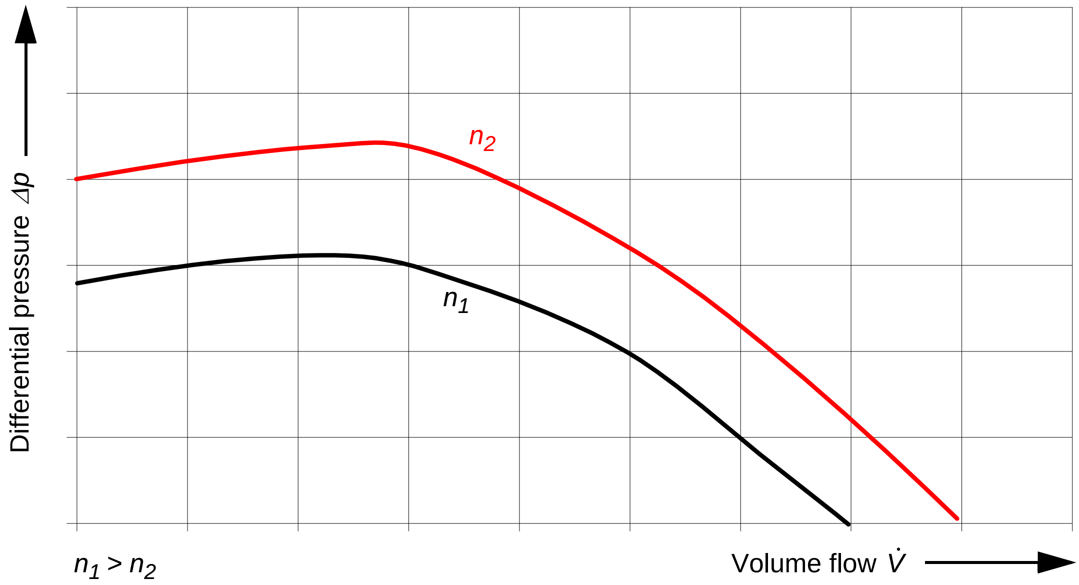


Fig. 4.3 Fan characteristic curves with different speeds n_1 and n_2

Due to the different speeds, the air particles entrained in the impeller are each given different kinetic energies. The subsequent decrease in the kinetic energies due to the increasing flow cross-section in the spiral housing of the fan causes the pressure energy to increases as a function of the speed.

4.4.3 System characteristic curve

The system characteristic curve shows the pressure drop (differential pressure) Δp, caused by all the flow resistances R of the air duct to the fan outlet, as a function of the volume flow $\dot{V}$.

Different system characteristic curves arise when the flow resistance is altered, for example by opening or closing a valve.

When recording a system curve, the volume flow $\dot{V}$ will be altered by the change in speed n. In doing so the internal components may not be modified, because this would amount to a change in the flow resistance R, and thus the resistance coefficients ζ.

- The system characteristic curve shows the volume flows $\dot{V}$ at different pressures p.
- Each pressure value prefers to a certain volume flow $\dot{V}$.
- The differential pressure Δp is dependent on the fan speed n.
- The differential pressure Δp is proportional to the square of the volume flow $\dot{V}$.

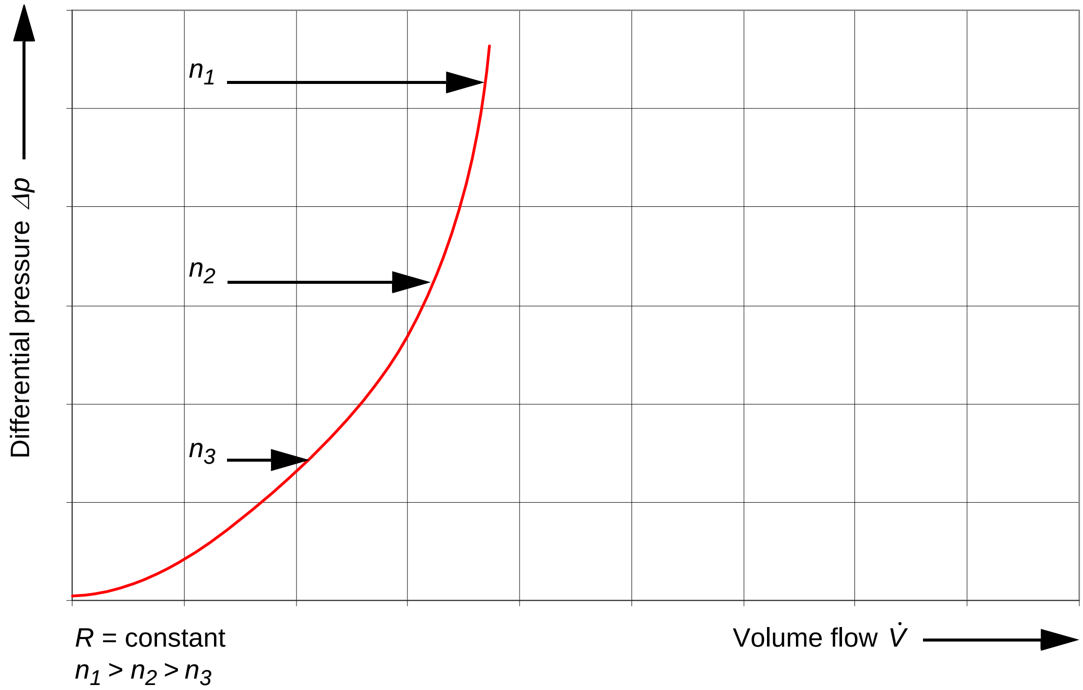


Fig. 4.4 System characteristic curve at constant flow resistance R

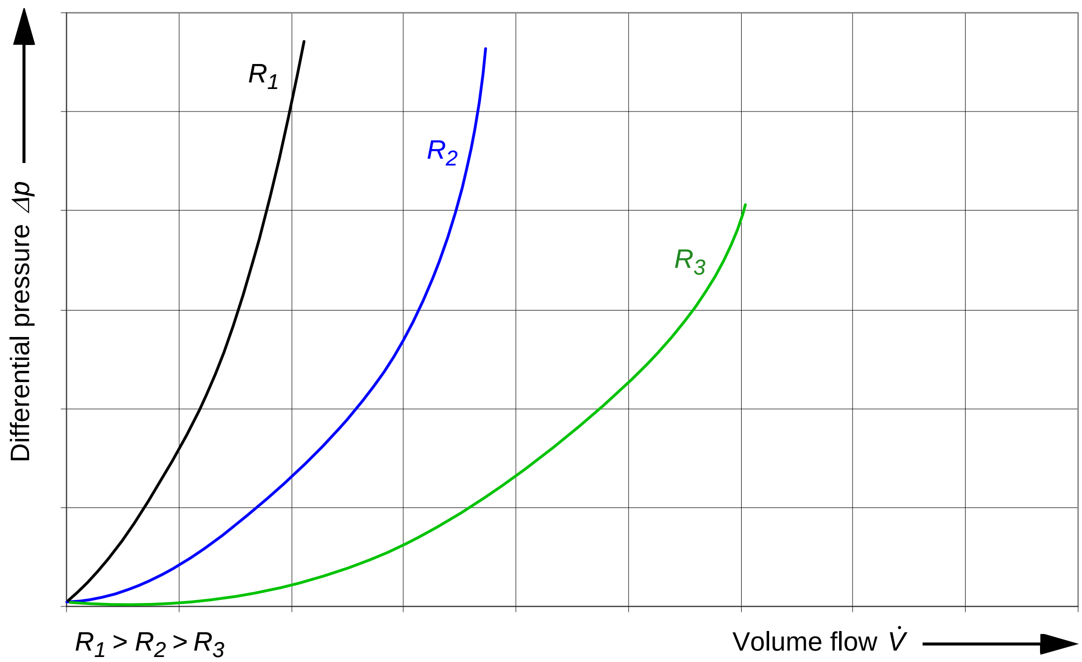


Fig. 4.5 System characteristic curve at different flow resistance R

4.4.4 Operating point

The **operating point** of a fan appears at the point where the differential pressures of fan and system are equal size, thus at the **intercept point of the system curve and the fan curve** (see Fig. 4.6).

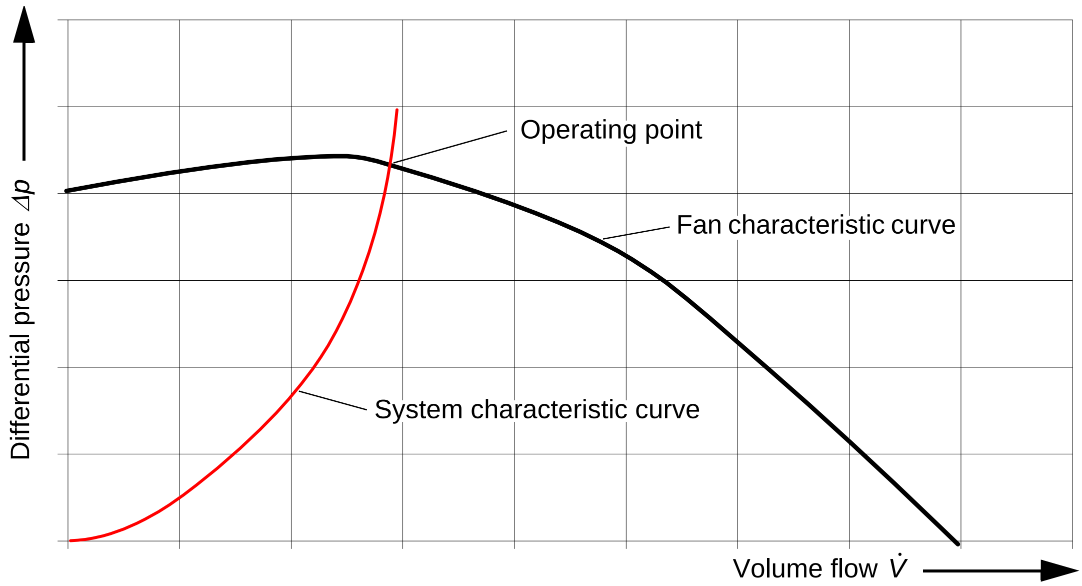


Fig. 4.6 Operating point

The position of the **operating point** can be altered

- via the **fan speed *n*** (see Fig. 4.7),
- or via the **flow resistance *R*** (see Fig. 4.8)**,** for example by changing the throttle valve position.

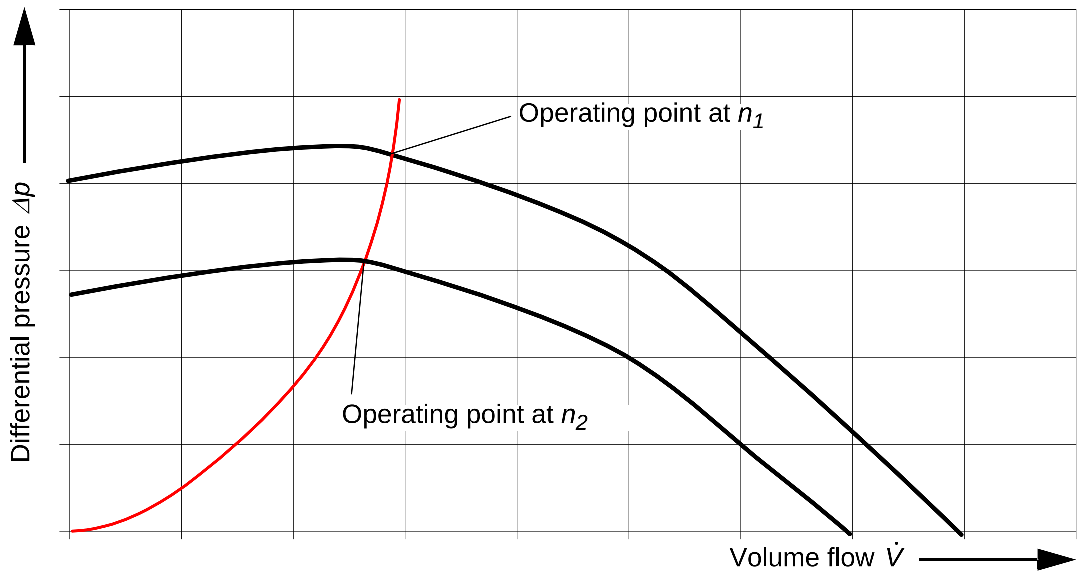


Fig. 4.7 Changing the operating point via the speed n

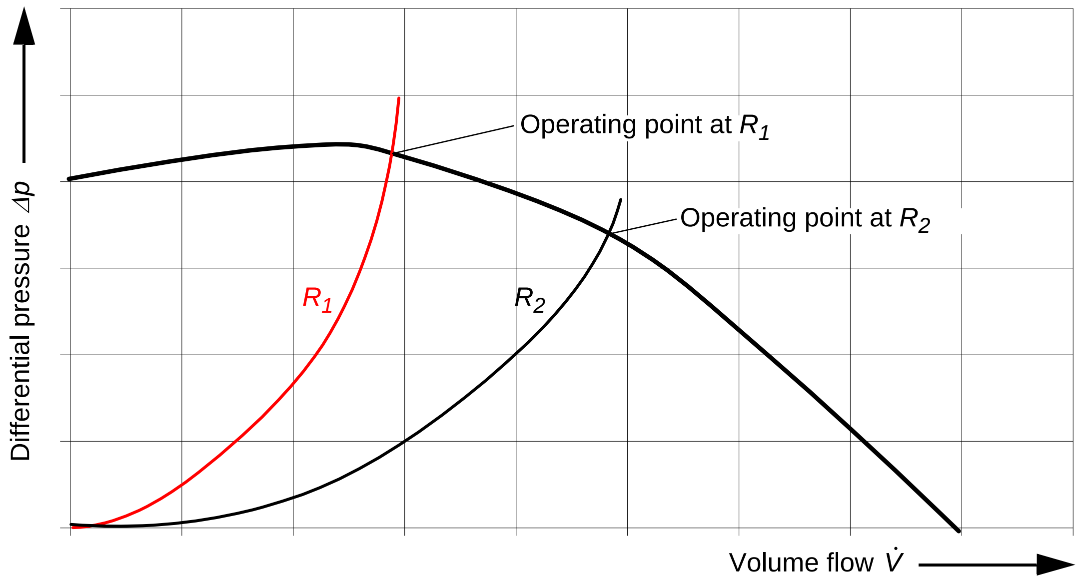


Fig. 4.8 Changing the operating point via the flow resistance R

4.4.5 Efficiency

To determine the volume flow that is drawn in, the total pressure p_{total} and static pressure p_{stat} are measured after the inflow into the intake port. From this we can calculate:

- the **dynamic pressure** p_{dyn} see Formula (4.1), Page 27
- the **flow velocity** v see Formula (4.2), Page 28
- the **volume flow** $\dot{V}$ see Formula (4.3), Page 28.

To determine the **supply pressure**, the pressure difference between the static pressure p_s at the suction side of the fan and the static pressure p_p at the pressure side of the fan is measured.

$$\Delta p = p_s - p_p \tag{4.9}$$

p_s	Pressure at the suction side of the fan
p_p	Pressure at the pressure side of the fan

The **delivered hydraulic power** (capacity) can be calculated from the volume flow and the total pressure increase (consisting of static and dynamic portions). Generally, the dynamic portion is considered if the speeds in the suction-side cross-section A_s and in the pressure-side cross-section A_p are of different sizes. This is the case when the cross-section areas A_s and A_p are different sizes.

$$P_{hydr} = \dot{V} \cdot p \tag{4.10}$$

$$P_{hydr} = \dot{V} \cdot \left[(p_p - p_s) + \frac{\varrho}{2} \cdot (v_p^2 - v_s^2) \right] \tag{4.11}$$

P_{hydr}	Hydraulic power
p_p	Pressure at the pressure side of the fan
p_s	Pressure at the suction side of the fan

The **supplied electrical power** is calculated as follows:

$$P_{el} = U \cdot I \tag{4.12}$$

P_{el}	Electrical power
U	Voltage
I	Current

The **fan efficiency** η is obtained from the ratio of the delivered hydraulic power to the supplied electrical power.

$$\eta = \frac{P_{hydr}}{P_{el}} \tag{4.13}$$

5 Tasks

5.1 Worksheet A – Components of the air duct system

Page 1

Objective

To recognise and name the components of an air duct system

Exercise

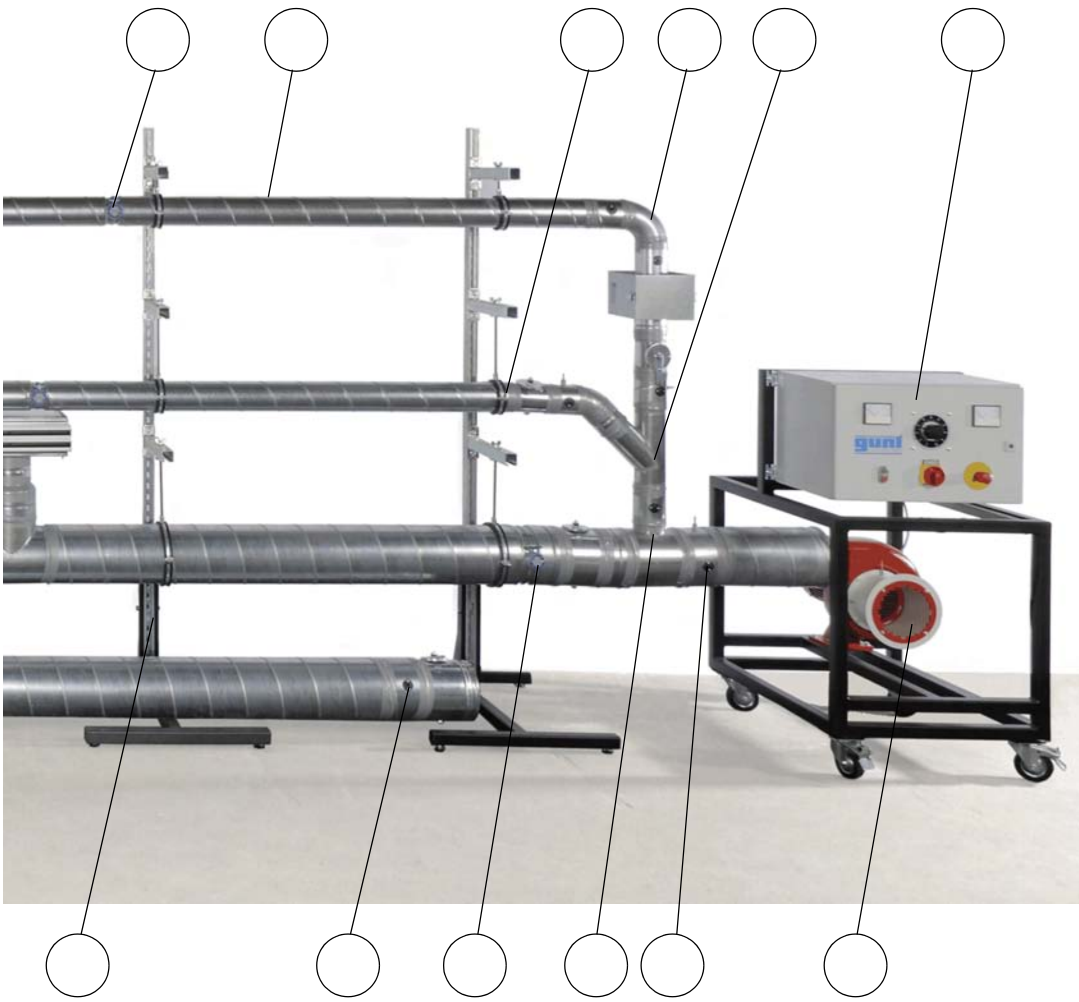
1. On the following page you will see a section of an air duct system.

   Enter the item numbers of the components from the table in the image.

Worksheet A – Components of the air duct system

Page 2

Item number	Component
1	Fan
2	Control cabinet
3	Assembly stand
4	Pipe clamp
5	Pipe
6	Bends and branches
7	Pressure measuring points
8	Iris



Worksheet A – Components of the air duct system

Page 3

2. Here you can see some components that can be fitted to the air duct.
   Enter the names of the components in table.


Item 1


Item 2


Item 3


Item 4


Item 5


Item 6


Item 7


Item 8

Item number	Component
1	
2	
3	
4	
5	
6	
7	
8	

5.2 Worksheet B – Assembling a complex air duct system

Page 1

Objective

- To assemble an air duct system
- To recognise possible pressure measurements

Exercise

On the following pages you will see a complex air duct system, represented as

- Illustration
- Piping diagram
- Parts list
- List of measuring points.

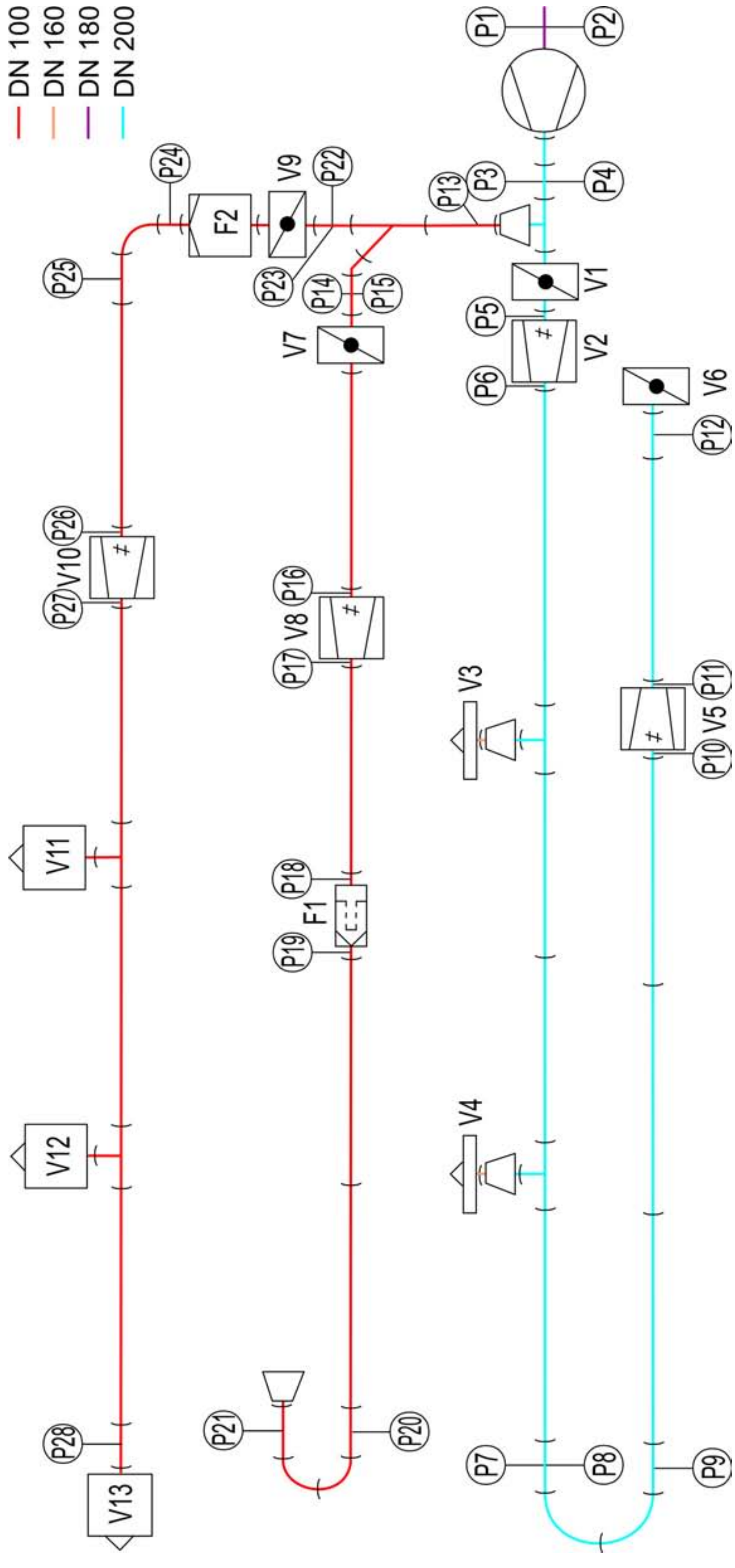
Worksheet B – Assembling a complex air duct system

Page 2

Illustration

Worksheet B – Assembling a complex air duct system

Page 3

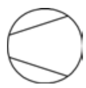
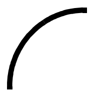
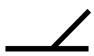


Piping diagram

Worksheet B – Assembling a complex air duct system

Page 4

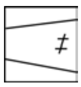
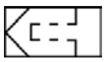
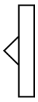
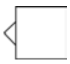
Parts list, part 1

Symbol	Name	Nominal diameter	Quan-tity	Identifi-cation letter
	Fan		1	
	Assembly stand		5	
	Pipe, length 1600 mm	DN 100	8	
		DN 200	8	
	Sleeve	DN 100	5	
		DN 160	2	
		DN 200	5	
	Plug connector	DN 100	4	
		DN 200	7	
	45° bend	DN 100	1	
	90° bend	DN 100	3	
		DN 200	2	
	45° branch	DN 100	1	
	90° branch	DN 100	2	
		DN 200	2	
	90° branch with reducer	DN 200 - DN 100	1	

Worksheet B – Assembling a complex air duct system

Page 5

Parts list, part 2

Symbol	Name	Nominal diameter	Quan-tity	Identifi-cation letter
	Reducer	DN 200 - DN 160	2	
		DN 160 - DN 100	1	
	Throttle valve	DN 100	2	V7, V9
		DN 200	2	V1, V6
	Iris	DN 100	2	V8, V10
		DN 200	2	V2, V5
	Pipe with measuring point for static pressure	DN 100	6	
		DN 200	2	
	Pipe with measuring point for static pressure and measuring point for total pressure	DN 100	2	
		DN 180	1	
		DN 200	2	
	Pocket filter	DN 100	1	F1
	Filter (filter matting)	DN 100	1	F2
	Linear diffuser	DN 160	2	V3, V4
	Outlet valve	DN 100	3	V11, V12, V13
	Adhesive tape			

Worksheet B – Assembling a complex air duct system

Page 6

List of measuring points

Type of measuring point	Measuring point identification letter	Nominal diameter of the pipe	Cross-section area of the pipe
Measuring point for static pressure	P13, P14, P16, P17, P18, P19, P20, P21, P22, P24, P25, P26, P27, P28	DN 100	7.854 mm^2
	P1	DN 180	25.447 mm^2
	P3, P5, P6, P7, P9, P10, P11, P12	DN 200	31.416 mm^2
Measuring point for total pressure	P15, P23	DN 100	7.854 mm^2
	P2	DN 180	25.447 mm^2
	P4, P8	DN 200	31.416 mm^2

Worksheet B – Assembling a complex air duct system

Page 7

1. Assemble the system shown from the components of the HL 710 air duct system and tightly seal the joints with tape.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

This experiment layout is the basis for the worksheets in Chapter 5.3, Page 52, to Chapter 5.11, Page 101.

2. Pressure measurement points are shown in the piping diagram on Page 47.

   Which pressure measurements could you perform on this system? Name the measuring points and the purpose of each measurement.

Pressure measuring points	Purpose of the measurement
Example: P3 and P12	Pressure drop across the lower pipeline at different volume flows.

5.3 Worksheet C – Two methods for determining the dynamic pressure

Page 1

Objective

- To measure dynamic pressure as differential pressure
- To measure total pressure and static pressure and to calculate the dynamic pressure
- To compare results of both methods
- Familiarisation with the digital manometer

Measuring equipment

- Digital manometer

Worksheet C – Two methods for determining the dynamic pressure

Page 2

Preparation for the experiment

1. Assemble the experiment setup according to Page 46 to Page 50.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the upper pipeline is considered. The lower and middle pipelines are shut off. Proceed as follows:
   – Set the throttle valves V1, V6 and V7 to position 0 (closed).
   – Set the irises V2, V5 and V8 to position 1 (closed).
   – Close the linear diffusers V3 and V4.
   – Set the throttle valve V9 to position 9 (open).
   – Set the iris V10 to position 6 (open).
   – Screw out the plates of the outlet valves V11, V12 and V13 a bit.

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

Worksheet C – Two methods for determining the dynamic pressure

Page 3

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

4. Turn the main switch on.
5. Turn the fan switch on.
6. Turn the rotation speed control knob to 100 %.

Worksheet C – Two methods for determining the dynamic pressure

Page 4

Exercise

1. Measuring dynamic pressure as differential pressure
   - Use the digital manometer to measure the differential pressure between measuring point P22 and measuring point P23.

     This differential pressure corresponds to the dynamic pressure p_{dyn1}.
   - Note down the measurement result:

Measuring points 22 and 23
Dynamic pressure p_{dyn1} in Pa

Worksheet C – Two methods for determining the dynamic pressure

Page 5

2. Measuring total pressure and static pressure and from this calculating the dynamic pressure
   - Use the digital manometer to measure the total pressure at measuring point P23 and note down the measured value in the table below.
   - Use the digital manometer to measure the static pressure at measuring point P22 and note down the measured value.
   - Calculate the difference between total pressure and static pressure. This is the dynamic pressure p_{dyn2}.

   Measurements:

Measuring point 23	Measuring point 22	Measuring points 22 and 23
Total pressure p_{total} in Pa	**Static pressure p_{stat} in Pa**	**Dynamic pressure p_{dyn2} in Pa**

3. Comparing both dynamic pressures

   Compare the dynamic pressure p_{dyn1} from task 1 with the dynamic pressure p_{dyn2} from task 2.

5.4 Worksheet D – Two methods for determining the flow velocity

Page 1

Objective

- Familiarisation with measuring the flow velocity
- Familiarisation with measuring dynamic pressure as differential pressure
- To calculate the flow velocity from the dynamic pressure
- To compare measured and calculated flow velocities
- Familiarisation with the anemometer

Measuring equipment

- Digital manometer
- Anemometer

Worksheet D – Two methods for determining the flow velocity

Page 2

Preparation for the experiment

1. Assemble the experiment setup according to Page 46 to Page 50.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the lower pipeline is considered. The middle and upper pipelines are shut off. To do this, proceed as follows:
   - Set the throttle valves V7 and V9 to position 0 (closed).
   - Set the irises V8 and V10 to position 1 (closed).
   - Close the linear diffusers V3 and V4.
   - Close the outlet valves V11, V12 and V13.
   - Set the throttle valves V1 and V6 to position 9 (open).
   - Set the irises V2 and V5 to position 6 (open).

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

Worksheet D – Two methods for determining the flow velocity

Page 3

WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120V: max 12,5A
  230V: max 6A

4. Turn the main switch on.
5. Turn the fan switch on.

Worksheet D – Two methods for determining the flow velocity

Page 4

Exercise

1. Taking measurements

   Set the rotation speed control knob to 100% and take the following measurements:

   - Use the digital manometer to measure the differential pressure between measuring points P7 and P8. This is the dynamic pressure at measuring point P8. Note down the value in the table on the next page.
   - Use the anemometer to measure the flow velocity at the outlet of the lower pipeline. Note down the value in the table.

   Gradually reduce the position of the rotation speed control knob and repeat the measurements. Note down your measurement results in the table on the following page.

Worksheet D – Two methods for determining the flow velocity

Page 5

2. Calculation

   Calculate the flow velocities from the dynamic pressures at measuring point P8 and enter the results in the table.

Rotation speed control knob	Measuring point P8		Outlet of the lower pipeline
in %	Dynamic pressure p_{P8} in Pa	Flow velocity v calculated in m/s	Flow velocity v measured in m/s

Worksheet D – Two methods for determining the flow velocity

Page 6

3. Comparison

   Compare the measured and calculated flow velocities and evaluate the differences.

Worksheet D – Two methods for determining the flow velocity

Page 7

4. Improving the measurements

   With which measurements at the measuring points P8 and at the outlet of the lower pipeline could you achieve better results?

5.5 Worksheet E – Two methods for determining the volume flow

Page 1

Objective

- Familiarisation with the volume flow at outlet valves
- Familiarisation with measuring dynamic pressure as differential pressure
- To calculate the volume flow from the dynamic pressure
- To compare measured and calculated volume flows

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 46 to Page 50.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the upper pipeline is considered. The lower and middle pipelines are shut off. Proceed as follows:
   - Set the throttle valves V1, V6 and V7 to position 0 (closed).
   - Set the irises V2, V5 and V8 to position 1 (closed).
   - Close the linear diffusers V3 and V4.
   - Set the throttle valve V9 to position 9 (open).
   - Set the iris V10 to position 6 (open).

Worksheet E – Two methods for determining the volume flow

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet E – Two methods for determining the volume flow

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120V: max 12,5A
  230V: max 6A

4. Turn the main switch on.
5. Turn the fan switch on.
6. Set the rotation speed control knob to 100%.

Worksheet E – Two methods for determining the volume flow

Page 4

Exercise

1. Measuring flow rates at outlet valves

- Screw out the plates of the outlet valves V11, V12 and V13 all the way, so that all three outlet valves are open simultaneously.
- Use the anemometer and the volume flow hood to measure the volume flow at the outlet valves V11, V12 and V13.

Note down the measurement results in the following table:

Outlet valve V11	Outlet valve V12	Outlet valve V13
Volume flow $\dot{V}_{V11}$ in ltr/s	**Volume flow $\dot{V}_{V12}$ in ltr/s**	**Volume flow $\dot{V}_{V13}$ in ltr/s**

Worksheet E – Two methods for determining the volume flow

Page 5

- Screw the plates back into the outlet valves V11, V12 and V13.
- Turn the plates in or out until you are measuring the same volume flow at all three outlet valves.

Note down the measurement results as an aid:

Outlet valve V11	Outlet valve V12	Outlet valve V13
Volume flow $\dot{V}_{V11}$ in ltr/s	Volume flow $\dot{V}_{V12}$ in ltr/s	Volume flow $\dot{V}_{V13}$ in ltr/s
Adjusted, same volume flow at the exhaust valves V11, V12 and V13		
Sum of the volume flow at the outlet valves V11, V12 and V13 $\dot{V}_{sum}$		

Worksheet E – Two methods for determining the volume flow

Page 6

2. Measuring dynamic pressure

- Use the digital manometer to measure the differential pressure between measuring point P22 and measuring point P23.

  This differential pressure corresponds to the dynamic pressure.

- Note down the measurement result in the table.

Measuring point 23
Dynamic pressure p_{dyn} in Pa

Worksheet E – Two methods for determining the volume flow

Page 7

3. Calculating volume flow

   Calculate the volume flow from the dynamic pressure at the measuring point P23.

   Your calculation result:

   $\dot{V}_{calc}$ =

Worksheet E – Two methods for determining the volume flow

Page 8

4. Comparing measured and calculated volume flow

   The volume flow $\dot{V}_{sum}$ you calculated in task 1 is:

   ____

   The volume flow $\dot{V}_{calc}$ you measured in task 2 is:

   ____

   Compare the two volume flows. Explain the different values.

   ____
   ____
   ____
   ____
   ____
   ____

   How could you improve the measurement of the dynamic pressure to get better results for the calculated volume flow $\dot{V}_{calc}$?

   ____
   ____
   ____
   ____
   ____

5.6 Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 1

Objective

- To measure the pressure loss of a composite 180° bend
- To calculate the resistance coefficient of the bend
- Familiarisation with an inclined tube manometer

Measuring equipment

- Inclined tube manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 46 to Page 50.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the lower pipeline is considered. The middle and upper pipelines are shut off. To do this, proceed as follows:
   - Set the throttle valves V7 and V9 to position 0 (closed).
   - Set the irises V8 and V10 to position 1 (closed).
   - Close the linear diffusers V3 and V4.
   - Close the outlet valves V11, V12 and V13.
   - Set the throttle valves V1 and V6 to position 9 (open).
   - Set the irises V2 and V5 to position 6 (open).

Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

4. Turn the main switch on.
5. Turn the fan switch on.

Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 4

Exercise

1. Measuring

   Set the rotation speed control knob to 100%.

   Take the following measurements:

   - Use the inclined tube manometer to measure the differential pressure between measuring points P7 and P9. This is the differential pressure across the composite 180° bend.
   - Use the anemometer to measure the flow velocity at the outlet of the lower pipeline.

   Gradually reduce the position of the rotation speed control knob and repeat the measurements.

   Note down your measurement results in the table on the following page.

Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 5

2. Calculating

From the differential pressure $\Delta p_{P7\text{-}P9}$ and the flow velocity at the outlet, calculate the resistance coefficient of the composite 180° bend and enter the results into the table.

What is the relationship between flow velocity and resistance coefficient?

Rotation speed control knob	Measuring point P7 - measuring point P9	Outlet of the lower pipeline	Composite 180°-bend
in %	Differential pressure $\Delta p_{P7\text{-}P9}$ in Pa	Flow velocity v in m/s measured	Resistance coefficient ζ

5.7 Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 1

Objective

- To measure the pressure loss over a 90° bend
- To measure the volume flow
- To draw and evaluate the characteristic curve of the pressure loss over the volume flow

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 46 to Page 50.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the upper pipeline is considered. The lower and middle pipelines are shut off. To do this, proceed as follows:
   - Set the throttle valves V1, V6 and V7 to position 0 (closed).
   - Set the irises V2, V5 and V8 to position 1 (closed).
   - Close the linear diffusers V3 and V4.
   - Set the throttle valve V9 to position 9 (open).
   - Screw out the plates of the outlet valves V11, V12 and V13 a bit.

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120V: max 12,5A
  230V: max 6A

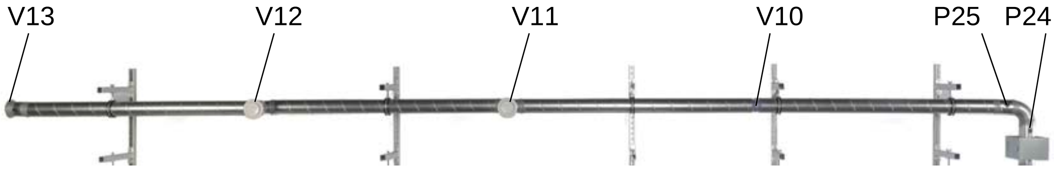
4. Turn the main switch on.
5. Turn the fan switch on.
6. Turn the rotation speed control knob to 100%.

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 4

Exercise

1. Taking measurements



- Set the iris V10 to position 1 (closed).
- Take the following measurements:
  - Use the digital manometer to measure the differential pressure between measuring points P24 and P25. This is the differential pressure across the 90° bend.
  - Use the anemometer and the volume flow hood to measure the volume flow at the outlet valves V11, V12 and V13. Generate the sum of the three volume flows.

  Gradually change the position of the iris V10 from position 1 (closed) to position 6 (open) and repeat each of the measurements.

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

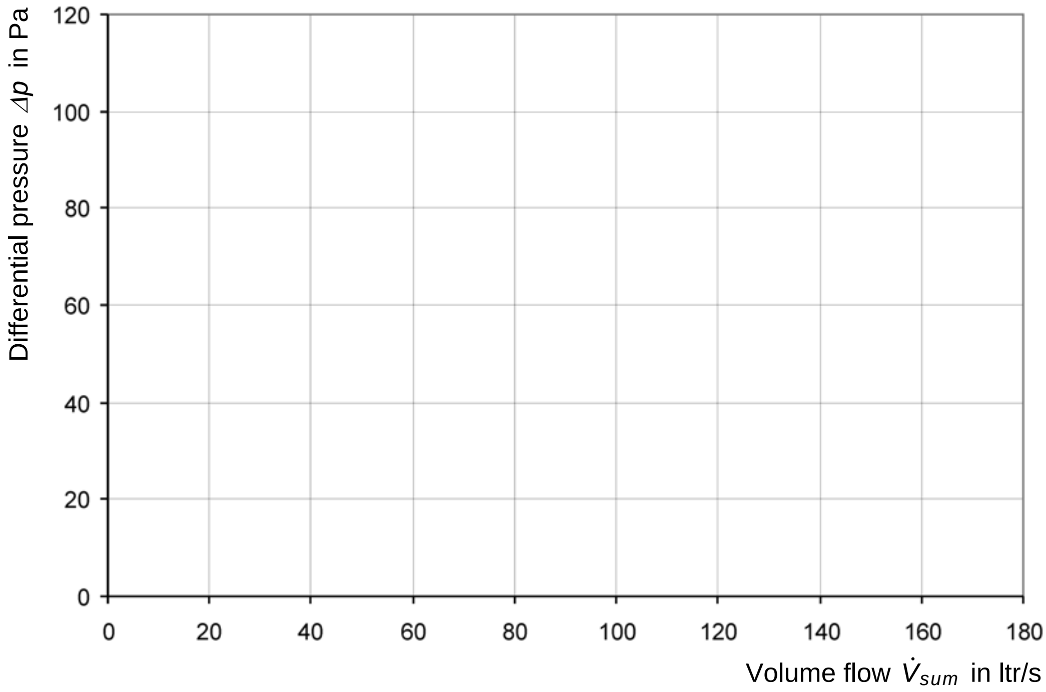
Page 5

Iris	Measuring point P24 - measuring point P25	Outlet valve V11	Outlet valve V12	Outlet valve V13	Sum V11, V12 and V13
Position	Differential pressure $\Delta p_{P24\text{-}P25}$ in Pa	Volume flow $\dot{V}_{V11}$ in ltr/s	Volume flow $\dot{V}_{V12}$ in ltr/s	Volume flow $\dot{V}_{V13}$ in ltr/s	Total volume flow $\dot{V}_{sum}$ in ltr/s

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 6

2. Enter the values for the differential pressure across the total volume flow in a chart and plot the curve.



3. Evaluate the characteristics of the curve.

5.8 Worksheet H – Characteristic curve of the pressure loss over a filter

Page 1

Objective

- Familiarisation with throttling via iris and via rotation speed control knob
- To determine the pressure loss over a filter

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 46 to Page 50.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the middle pipeline is considered. The lower and upper pipelines are shut off. To do this, proceed as follows:
   – Set the throttle valves V1, V6 and V9 to position 0 (closed).
   – Set the irises V2, V5 and V10 to position 1 (closed).
   – Close the disc valves V11, V12 and V13.
   – Close the linear diffusers V3 and V4.
   – Install the filter element in the pocket filter F1.
   – Set the throttle valve V7 to position 9 (open).
   – Set the iris V8 to position 6 (open).

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

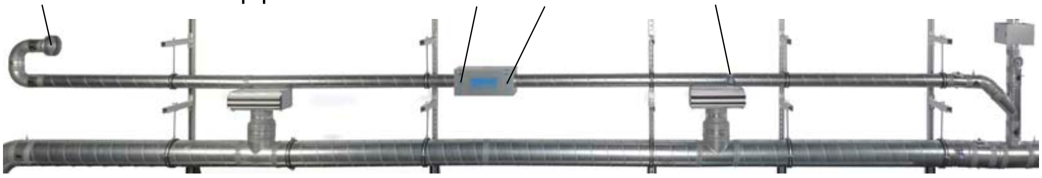
- Ensure that the following currents are complied with during continuous load:
  120V: max 12,5A
  230V: max 6A

4. Turn the main switch on.
5. Turn the fan switch on.
6. Turn the rotation speed control knob to 100%.

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 4

Exercise



1. Measurements with throttling via the iris
   - Use the digital manometer to measure the differential pressure between measuring points P19 and P18. This is the pressure loss across the filter F1.
   - Use the anemometer and the volume flow hood to measure the volume flow at the outlet of the middle pipeline.

   Gradually change the position of the iris V8 from position 6 (open) to position 1 (closed) and repeat each of the measurements.

Iris	**Measuring point P19 - measuring point P18**	**Outlet of the middle pipeline**
Position	**Differential pressure $\Delta p_{p19\text{-}p18}$ in Pa**	**Volume flow $\dot{V}$ in ltr/s**

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 5

2. Measurements with throttling via the rotation speed control knob
   - Set the iris V8 to position 6 (open).
   - Use the digital manometer to measure the differential pressure between measuring points P19 and P18. This is the pressure loss across the filter F1.
   - Use the anemometer and the volume flow hood to measure the volume flow at the outlet of the middle pipeline.

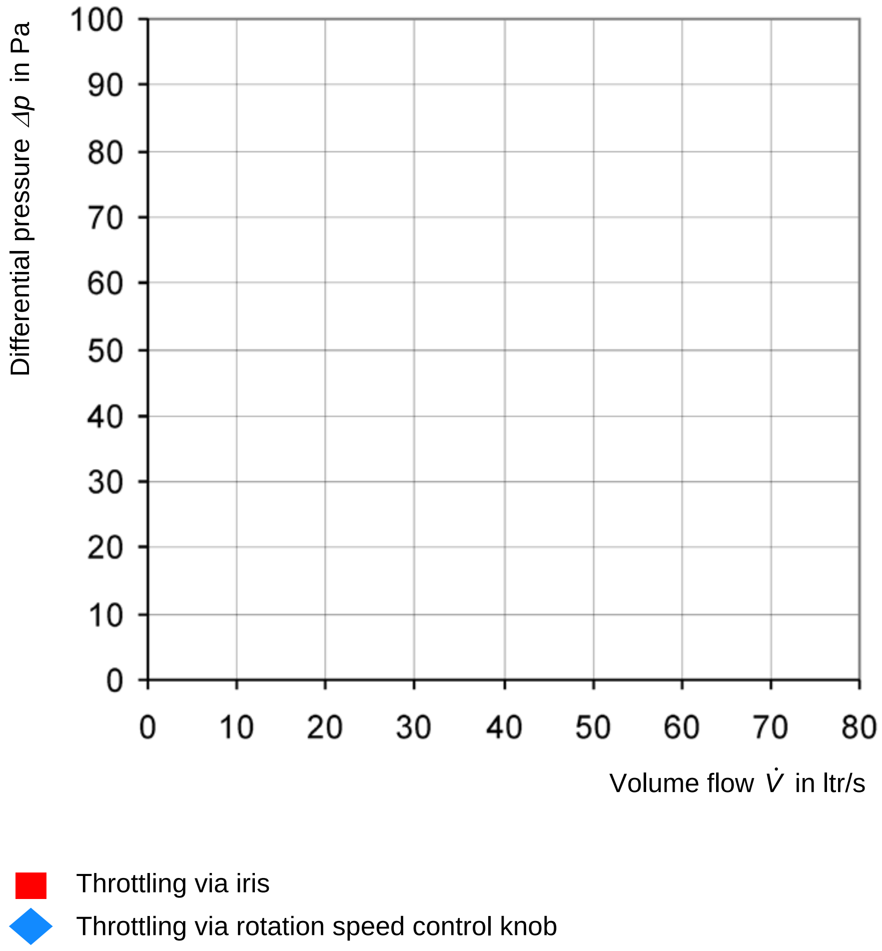
   Gradually reduce the position of the rotation speed control knob and repeat the measurements. Note down the results of your measurements in the following table.

Rotation speed control knob	Measuring point P19 - measuring point P18	Outlet of the middle pipeline
Position	Differential pressure $\Delta p_{p19\text{-}p18}$ in Pa	Volume flow $\dot{V}$ in ltr/s

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 6

3. Enter the values for the differential pressure across the volume flow in a chart and plot the curve.



4. Evaluate the characteristics of the curve.

5.9 Worksheet I – Characteristic curve of the lower pipeline

Page 1

Objective

- To measure the static pressure relative to atmospheric pressure
- To measure the volume flow
- To present and evaluate a pipeline's characteristic curve

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 46 to Page 50.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the lower pipeline is considered. The middle and upper pipelines are shut off. To do this, proceed as follows:
   - Set the throttle valves V7 and V9 to position 0 (closed).
   - Set the irises V8 and V10 to position 1 (closed).
   - Close the linear diffusers V3 and V4.
   - Close the outlet valves V11, V12 and V13.
   - Set the throttle valves V1 and V6 to position 9 (open).
   - Set the irises V2 and V5 to position 6 (open).

Worksheet I – Characteristic curve of the lower pipeline

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet I – Characteristic curve of the lower pipeline

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

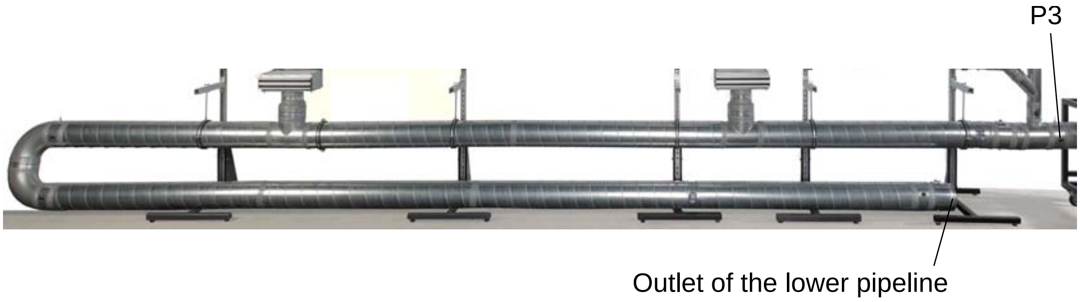
- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

4. Turn the main switch on.
5. Turn the fan switch on.

Worksheet I – Characteristic curve of the lower pipeline

Page 4

Exercise



1. Set the rotation speed control knob to 100% and take the following measurements:
   - Use the digital manometer to measure the static pressure at measuring point P3 relative to the atmospheric pressure.
   - Use the anemometer to measure the flow velocity at the outlet of the lower pipeline.

   Gradually reduce the position of the rotation speed control knob and repeat the measurements. Note down the results of your measurements in the table.

2. Calculate the volume flow from the flow velocity and enter the results into the table.

Worksheet I – Characteristic curve of the lower pipeline

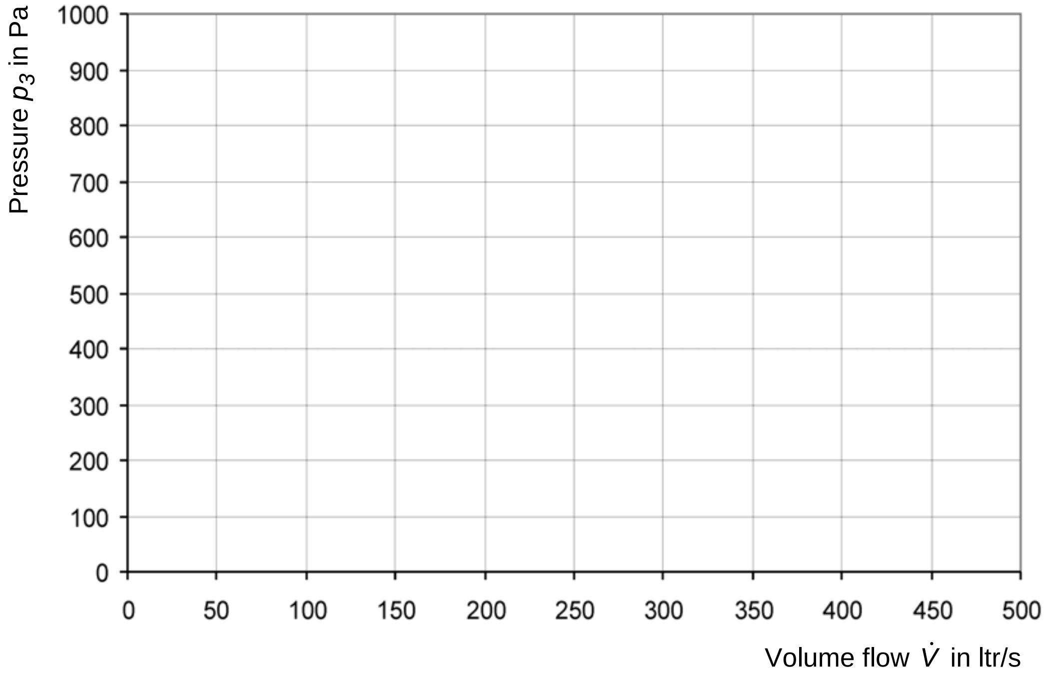
Page 5

Rotation speed control knob	Measuring point P3	Outlet of the lower pipeline	
in %	Static pressure p_{P3} in Pa	Flow velocity v measured in m/s	Total volume flow $\dot{V}$ in ltr/s

Worksheet I – Characteristic curve of the lower pipeline

Page 6

3. Enter the values for the pressure across the volume flow in a chart and plot the curve.



4. Is it a system characteristic curve?

___

___

___

5. Evaluate the characteristics of the curve.

___

___

___

5.10 Worksheet J – Throttle characteristic curve of the lower pipeline

Page 1

Objective

- To measure the static pressure relative to atmospheric pressure
- To measure the volume flow
- To represent a throttle characteristic curve

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 46 to Page 50.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the lower pipeline is considered. The middle and upper pipelines are shut off. To do this, proceed as follows:
   – Set the throttle valves V7 and V9 to position 0 (closed).
   – Set the irises V8 and V10 to position 1 (closed).
   – Close the linear diffusers V3 and V4.
   – Close the outlet valves V11, V12 and V13.
   – Set the throttle valves V1 and V6 to position 9 (open).
   – Set the irises V2 and V5 to position 6 (open).

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

4. Turn the main switch on.
5. Turn the fan switch on.

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 4

Exercise

1. Measurements

   Set the rotation speed control knob to 100% and take the following measurements:

   - Use the digital manometer to measure static pressure at measuring point P3 relative to the atmospheric pressure.
   - Use the anemometer to measure the flow velocity at the outlet of the lower pipeline.

   Gradually change the position of the throttle valve V6 from position 9 (open) to position 0 (closed) and repeat each of the measurements.

   Enter the measured values in the table.

2. Calculations

   Calculate the volume flow from the flow velocity at the outlet and enter the results into the table.

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 5

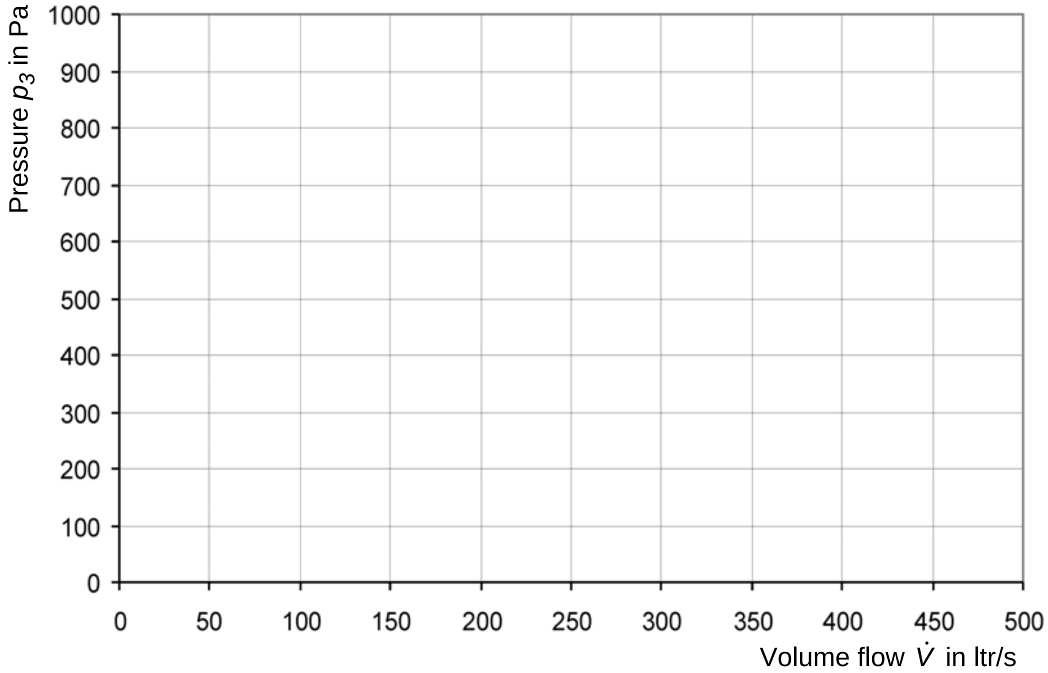
Throttle valve	Measuring point P3	Outlet of the lower pipeline	
Position	Static pressure p_{P3} in Pa	Flow velocity v measured in m/s	Total volume flow $\dot{V}$ in ltr/s

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 6

3. Characteristic curve

   - Enter the values for the pressure across the volume flow in a chart and plot the curve.



4. Comparison

   Compare the characteristic curve from Chapter 5.9, Page 89 (Worksheet I – Characteristic curve of the lower pipeline) with the characteristic curve on this page (Worksheet J – Throttle characteristic curve of the lower pipeline).

   What do the characteristic curves represent?

5.11 Worksheet K – Air distribution in the air duct system

Page 1

Objective

- To operate upper, middle and lower pipelines individually and in combination with each other
- To measure the volume flows at outlet valves
- To evaluate the air distribution

Measuring equipment

- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 46 to Page 50.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Create the starting state. To do this, proceed as follows:
   – Set the throttle valve V6 to position 9 (open).
   – Set the irises V2, V5, V8 and V10 to position 6 (open).
   – Close the linear diffusers V3 and V4.

Worksheet K – Air distribution in the air duct system

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet K – Air distribution in the air duct system

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

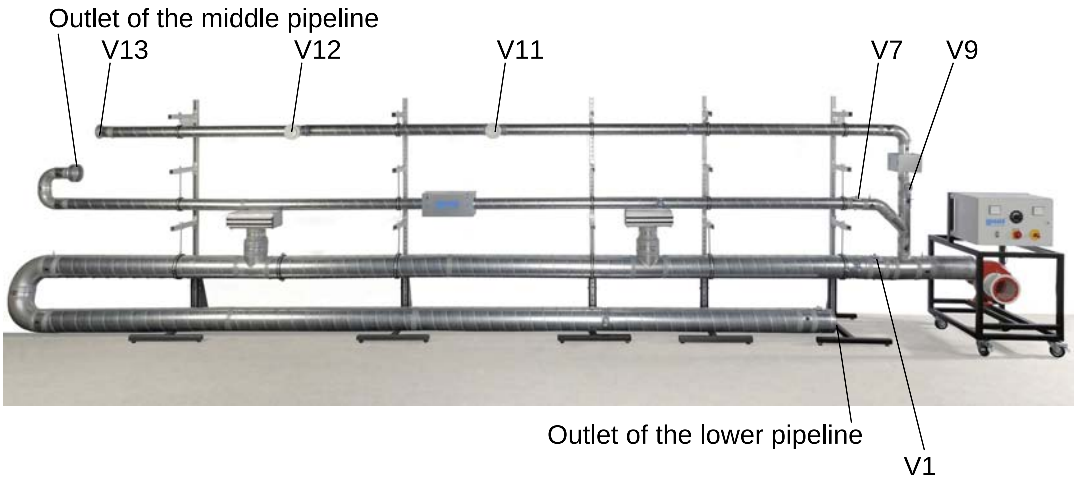
- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

4. Turn the main switch on.
5. Turn the fan switch on.
6. Turn the rotation speed control knob to 100 %.

Worksheet K – Air distribution in the air duct system

Page 4

Exercise



1. Opening or blocking individual pipelines

   From the table on the next page, select the desired settings and open or block the individual pipelines accordingly.

   - To open the upper pipeline:
     Set the throttle valve V9 to position 9 (open).
   - To block the upper pipeline:
     Set the throttle valve V9 to position 0 (closed).
   - To open the middle pipeline:
     Set the throttle valve V7 to position 9 (open).
   - To block the middle pipeline:
     Set the throttle valve V7 to position 0 (closed).
   - To open the lower pipeline:
     Set the throttle valve V1 to position 9 (open).
   - To block the lower pipeline:
     Set the throttle valve V1 to position 0 (closed).

Worksheet K – Air distribution in the air duct system

Page 5

2. Measurements

Use the anemometer and the volume flow hood to measure the volume flows at

- the outlet valves V11, V12 and V13
- the outlet of the middle pipeline
- the outlet of the lower pipeline

As the throttle valves do not fully seal the flow cross-section, the measurements must always be taken at all outlet valves and pipe outlets.

Note down the results of your measurements in the table.

Upper pipeline	Middle pipeline	Lower pipeline	Upper pipeline				Middle pipeline	Lower pipeline	Sum of all pipelines
			V11	V12	V13	Sum V11, V12 and V13	Outlet	Outlet	
			Volume flow $\dot{V}$ in ltr/s						
open	open	open							
open	open	closed							
open	closed	open							
open	closed	closed							
closed	open	open							
closed	open	closed							
closed	closed	open							
closed	closed	closed							

white: closed
yellow: open

Worksheet K – Air distribution in the air duct system

Page 6

3. Evaluate the measurement results.

6 Solutions

6.1 Worksheet A – Components of the air duct system

Page 1

Objective

To recognise and name the components of an air duct system

Exercise

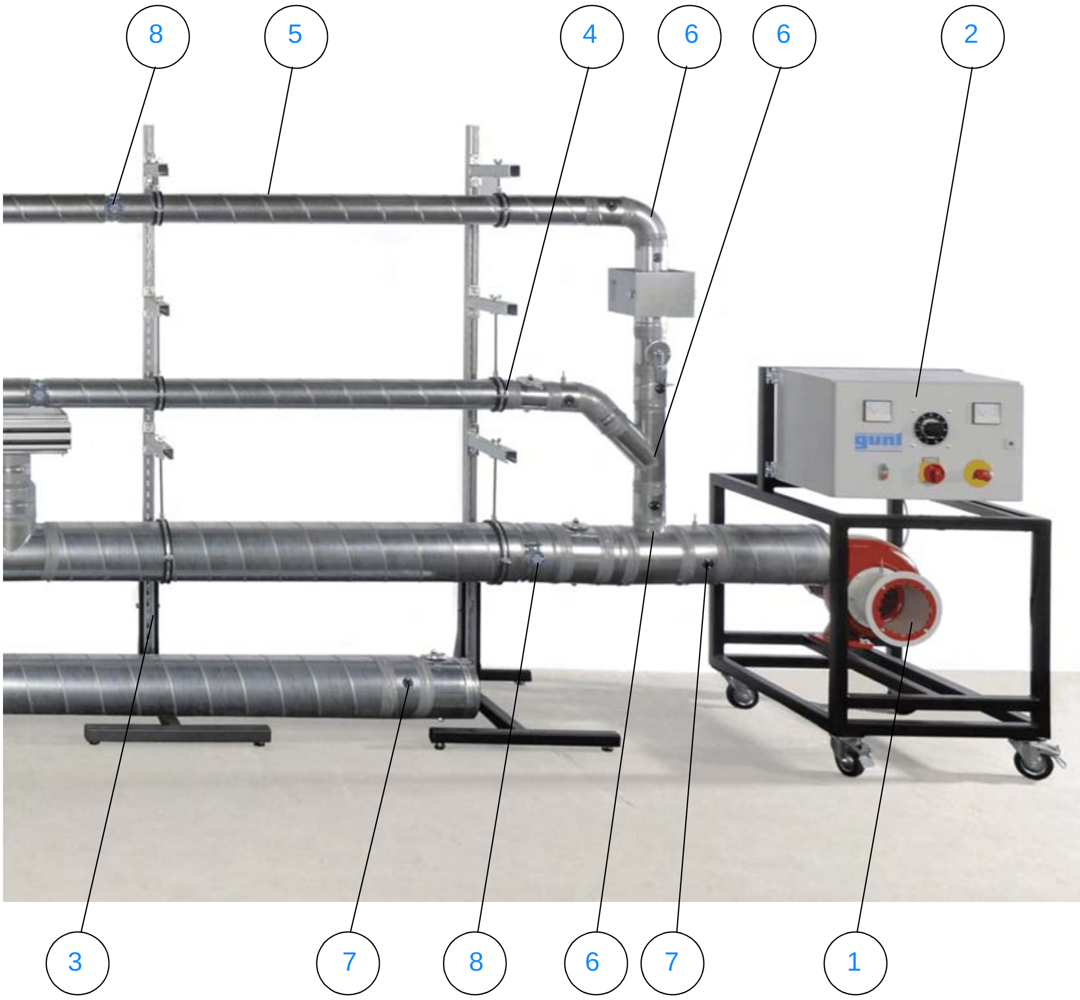
1. On the following page you will see a section of an air duct system.

   Enter the item numbers of the components from the table in the image.

Worksheet A – Components of the air duct system

Page 2

Item number	Component
1	Fan
2	Control cabinet
3	Assembly stand
4	Pipe clamp
5	Pipe
6	Bends and branches
7	Pressure measuring points
8	Iris



Worksheet A – Components of the air duct system

Page 3

2. Here you can see some components that can be fitted to the air duct.
   Enter the names of the components in table.


Item 1


Item 2


Item 3


Item 4


Item 5


Item 6


Item 7


Item 8

Item number	Component
1	Outlet valve
2	90° branch
3	Reducer
4	Filter cartridge for filter matting and pocket filter
5	90° bend and 45° bend
6	45° branch
7	Linear diffuser
8	90° branch with reducer

6.2 Worksheet B – Assembling a complex air duct system

Page 1

Objective

- To assemble an air duct system
- To recognise possible pressure measurements

Exercise

On the following pages you will see a complex air duct system, represented as

- Illustration
- Piping diagram
- Parts list
- List of measuring points.

Worksheet B – Assembling a complex air duct system

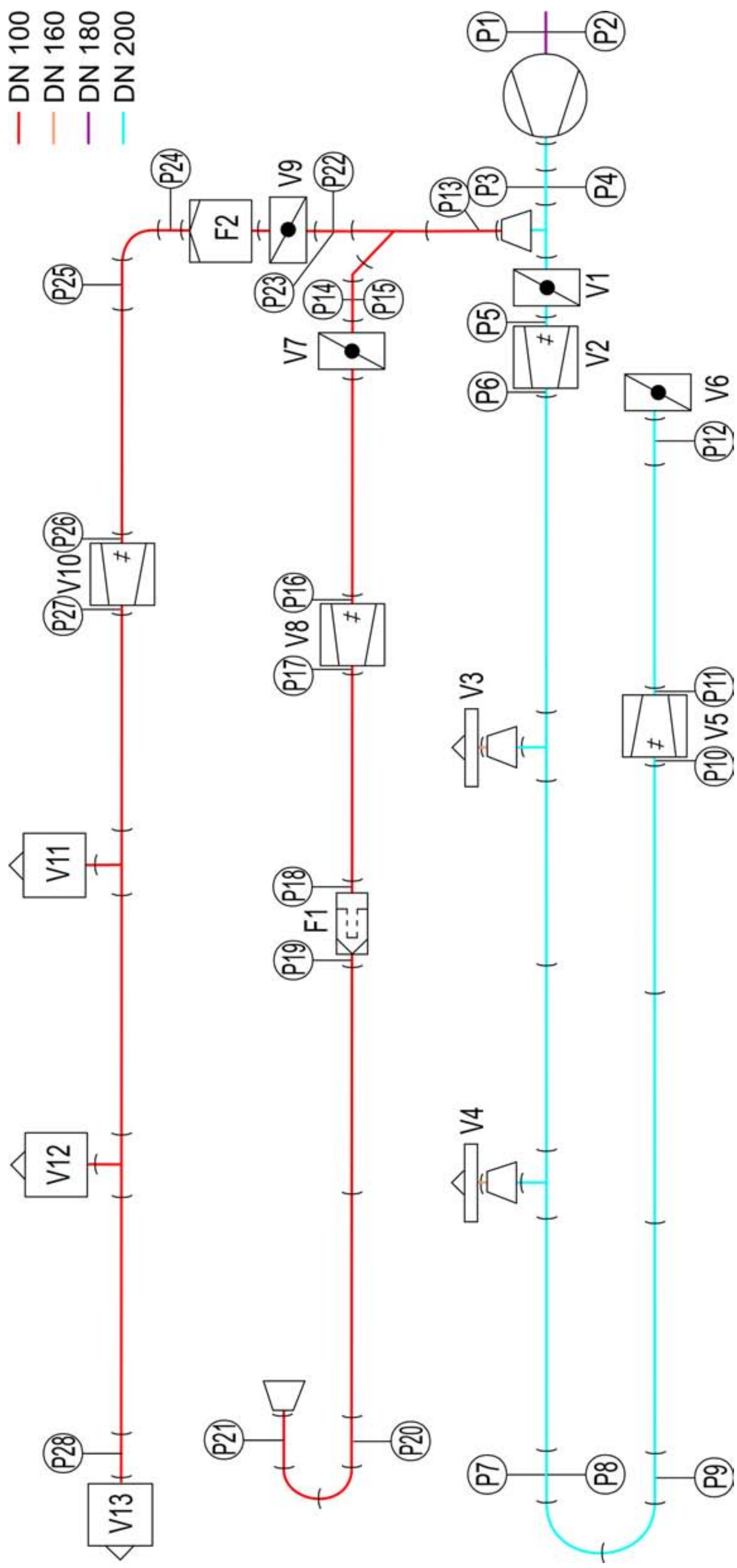
Page 2

Illustration

Worksheet B – Assembling a complex air duct system

Page 3

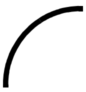
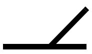
Piping diagram



Worksheet B – Assembling a complex air duct system

Page 4

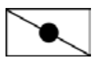
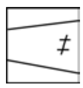
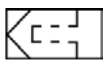
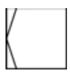
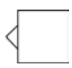
Parts list, part 1

Symbol	Name	Nominal diameter	Quan-tity	Identifi-cation letter
	Fan		1	
	Assembly stand		5	
	Pipe, length 1600 mm	DN 100	8	
		DN 200	8	
	Sleeve	DN 100	5	
		DN 160	2	
		DN 200	5	
	Plug connector	DN 100	4	
		DN 200	7	
	45° bend	DN 100	1	
	90° bend	DN 100	3	
		DN 200	2	
	45° branch	DN 100	1	
	90° branch	DN 100	2	
		DN 200	2	
	90° branch with reducer	DN 200 - DN 100	1	

Worksheet B – Assembling a complex air duct system

Page 5

Parts list, part 2

Symbol	Name	Nominal diameter	Quan-tity	Identifi-cation letter
	Reducer	DN 200 - DN 160	2	
		DN 160 - DN 100	1	
	Throttle valve	DN 100	2	V7, V9
		DN 200	2	V1, V6
	Iris	DN 100	2	V8, V10
		DN 200	2	V2, V5
	Pipe with measuring point for static pressure	DN 100	6	
		DN 200	2	
	Pipe with measuring point for static pressure and measuring point for total pressure	DN 100	2	
		DN 180	1	
		DN 200	2	
	Pocket filter	DN 100	1	F1
	Filter (filter matting)	DN 100	1	F2
	Linear diffuser	DN 160	2	V3, V4
	Outlet valve	DN 100	3	V11, V12, V13
	Adhesive tape			

Worksheet B – Assembling a complex air duct system

Page 6

List of measuring points

Type of measuring point	Measuring point identification letter	Nominal diameter of the pipe	Cross-section area of the pipe
Measuring point for static pressure	P13, P14, P16, P17, P18, P19, P20, P21, P22, P24, P25, P26, P27, P28	DN 100	7.854 mm^2
	P1	DN 180	25.447 mm^2
	P3, P5, P6, P7, P9, P10, P11, P12	DN 200	31.416 mm^2
Measuring point for total pressure	P15, P23	DN 100	7.854 mm^2
	P2	DN 180	25.447 mm^2
	P4, P8	DN 200	31.416 mm^2

Worksheet B – Assembling a complex air duct system

Page 7

1. Assemble the system shown from the components of the HL 710 air duct system and tightly seal the joints with tape.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

This experiment layout is the basis for the worksheets in Chapter 6.3, Page 118, to Chapter 6.11, Page 167.

2. Pressure measurement points are shown in the piping diagram on Page 113.

   Which pressure measurements could you perform on this system? Name the measuring points and the purpose of each measurement.

Pressure measuring points	Purpose of the measurement
Example: P3 and P12	Pressure drop across the lower pipeline at different volume flows.
P20 and P21	Differential pressure across composite 180° bend at different volume flows.
P10 and P11	Differential pressure across the iris at constant volume flow and different positions of the iris to determine the flow velocity.
P13, P14 and P22	Comparison of pressure drops in different flow directions of a branch at different volume flows.
P7 and P8	Measurement of the total pressure and static pressure, and calculation of the dynamic pressure and the flow velocity.
P14 and P16	Pressure loss through the throttle valve at different positions of the throttle valve.

6.3 Worksheet C – Two methods for determining the dynamic pressure

Page 1

Objective

- To measure dynamic pressure as differential pressure
- To measure total pressure and static pressure and to calculate the dynamic pressure
- To compare results of both methods
- Familiarisation with the digital manometer

Measuring equipment

- Digital manometer

Worksheet C – Two methods for determining the dynamic pressure

Page 2

Preparation for the experiment

1. Assemble the experiment setup according to Page 112 to Page 116.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the upper pipeline is considered. The lower and middle pipelines are shut off. Proceed as follows:
   - Set the throttle valves V1, V6 and V7 to position 0 (closed).
   - Set the irises V2, V5 and V8 to position 1 (closed).
   - Close the linear diffusers V3 and V4.
   - Set the throttle valve V9 to position 9 (open).
   - Set the iris V10 to position 6 (open).
   - Screw out the plates of the outlet valves V11, V12 and V13 a bit.

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

Worksheet C – Two methods for determining the dynamic pressure

Page 3

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

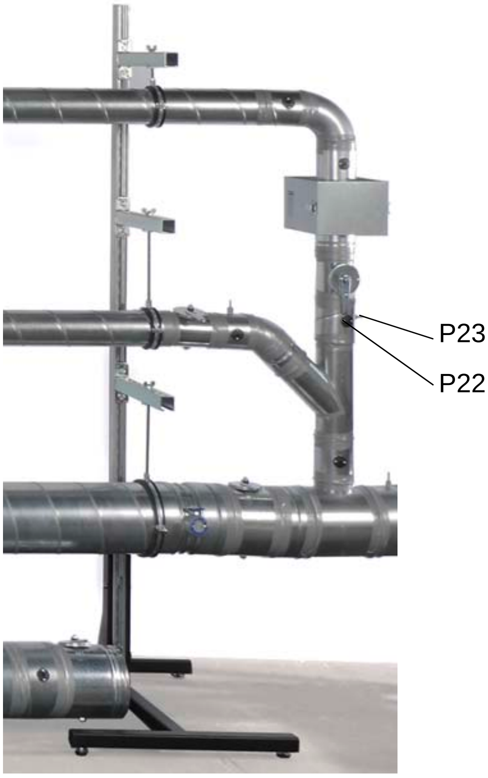
- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

4. Turn the main switch on.
5. Turn the fan switch on.
6. Turn the rotation speed control knob to 100%.

Worksheet C – Two methods for determining the dynamic pressure

Page 4

Exercise



1. Measuring dynamic pressure as differential pressure
   - Use the digital manometer to measure the differential pressure between measuring point P22 and measuring point P23.

     This differential pressure corresponds to the dynamic pressure p_{dyn1}.
   - Note down the measurement result:

Measuring points 22 and 23
Dynamic pressure p_{dyn1} in Pa
65

Worksheet C – Two methods for determining the dynamic pressure

Page 5

2. Measuring total pressure and static pressure and from this calculating the dynamic pressure
   - Use the digital manometer to measure the total pressure at measuring point P23 and note down the measured value in the table below.
   - Use the digital manometer to measure the static pressure at measuring point P22 and note down the measured value.
   - Calculate the difference between total pressure and static pressure. This is the dynamic pressure p_{dyn2}.

   Measurements:

Measuring point 23	Measuring point 22	Measuring points 22 and 23
Total pressure p_{total} in Pa	**Static pressure p_{stat} in Pa**	**Dynamic pressure p_{dyn2} in Pa**
800	738	62

3. Comparing both dynamic pressures

   Compare the dynamic pressure p_{dyn1} from task 1 with the dynamic pressure p_{dyn2} from task 2.

   p_{dyn1} is 65 Pa, p_{dyn2} is 62 Pa.

   The difference between the two values is 5%, thus it is small.

6.4 Worksheet D – Two methods for determining the flow velocity

Page 1

Objective

- Familiarisation with measuring the flow velocity
- Familiarisation with measuring dynamic pressure as differential pressure
- To calculate the flow velocity from the dynamic pressure
- To compare measured and calculated flow velocities
- Familiarisation with the anemometer

Measuring equipment

- Digital manometer
- Anemometer

Worksheet D – Two methods for determining the flow velocity

Page 2

Preparation for the experiment

1. Assemble the experiment setup according to Page 112 to Page 116.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the lower pipeline is considered. The middle and upper pipelines are shut off. To do this, proceed as follows:
   – Set the throttle valves V7 and V9 to position 0 (closed).
   – Set the irises V8 and V10 to position 1 (closed).
   – Close the linear diffusers V3 and V4.
   – Close the outlet valves V11, V12 and V13.
   – Set the throttle valves V1 and V6 to position 9 (open).
   – Set the irises V2 and V5 to position 6 (open).

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

Worksheet D – Two methods for determining the flow velocity

Page 3

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

4. Turn the main switch on.
5. Turn the fan switch on.

Worksheet D – Two methods for determining the flow velocity

Page 4

Exercise

1. Taking measurements

   Set the rotation speed control knob to 100% and take the following measurements:

   - Use the digital manometer to measure the differential pressure between measuring points P7 and P8. This is the dynamic pressure at measuring point P8. Note down the value in the table on the next page.
   - Use the anemometer to measure the flow velocity at the outlet of the lower pipeline. Note down the value in the table.

   Gradually reduce the position of the rotation speed control knob and repeat the measurements. Note down your measurement results in the table on the following page.

Worksheet D – Two methods for determining the flow velocity

Page 5

2. Calculation

Calculate the flow velocities from the dynamic pressures at measuring point P8 and enter the results in the table.

Rotation speed control knob	Measuring point P8		Outlet of the lower pipeline
in %	Dynamic pressure p_{P8} in Pa	Flow velocity v calculated in m/s	Flow velocity v measured in m/s
100	77	11,2	16,5
80	72	10,8	16,0
60	55	9,5	14,0
50	22	6,0	8,9
40	10	4,0	5,8
35	5	2,9	4,2

Calculation method:

$$v = \sqrt{\frac{2 \cdot p_{dyn}}{\rho}}$$

v Flow velocity
p_{dyn} Dynamic pressure
ρ Density of the flow medium
Air: 1,225 kg/m^3 at 15 °C

Worksheet D – Two methods for determining the flow velocity

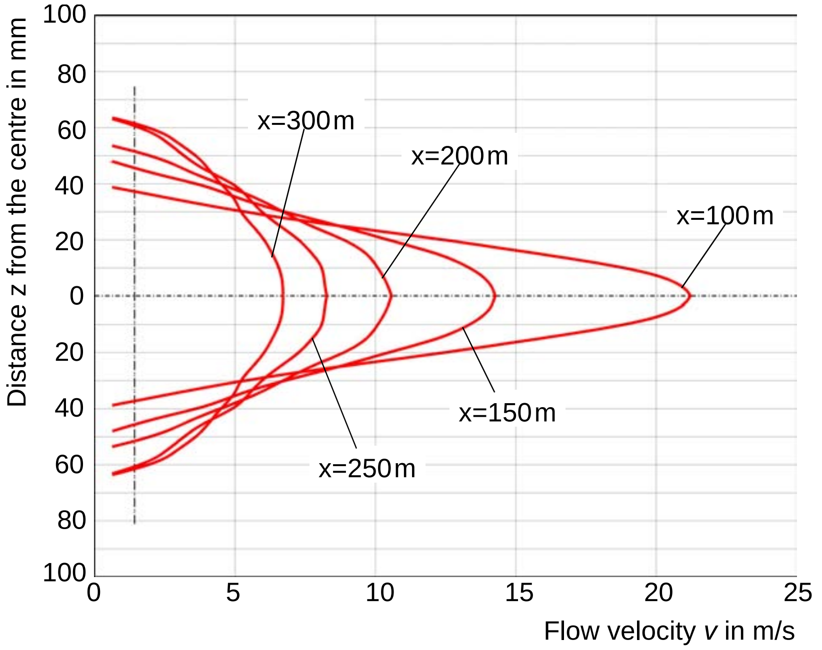
Page 6

3. Comparison

   Compare the measured and calculated flow velocities and evaluate the differences.

   The flow velocities measured at the outlet of the lower pipeline are higher than the flow velocities calculated for measuring point P8.

   Reason: In an open jet like at the outlet of the lower pipeline the flow velocity is highest at the middle of the open jet. With increasing horizontal and vertical distance from the centre, the flow velocity in the open jet decreases, see following example illustration.



x = horizontal distance from the pipe outlet

Fig. 6.1 Example velocity profile in the open jet of a pipe with 130 mm diameter

Worksheet D – Two methods for determining the flow velocity

Page 7

4. Improving the measurements

   With which measurements at the measuring points P8 and at the outlet of the lower pipeline could you achieve better results?

   - Option 1: Measure the flow velocity at different positions of the open jet and take the mean value from this.
   - Option 2: Measure the volume flow at the outlet of the lower pipeline with the anemometer and the volume flow hood.

6.5 Worksheet E – Two methods for determining the volume flow

Page 1

Objective

- Familiarisation with the volume flow at outlet valves
- Familiarisation with measuring dynamic pressure as differential pressure
- To calculate the volume flow from the dynamic pressure
- To compare measured and calculated volume flows

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 112 to Page 116.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the upper pipeline is considered. The lower and middle pipelines are shut off. Proceed as follows:
   - Set the throttle valves V1, V6 and V7 to position 0 (closed).
   - Set the irises V2, V5 and V8 to position 1 (closed).
   - Close the linear diffusers V3 and V4.
   - Set the throttle valve V9 to position 9 (open).
   - Set the iris V10 to position 6 (open).

Worksheet E – Two methods for determining the volume flow

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet E – Two methods for determining the volume flow

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120V: max 12,5A
  230V: max 6A

4. Turn the main switch on.
5. Turn the fan switch on.
6. Set the rotation speed control knob to 100%.

Worksheet E – Two methods for determining the volume flow

Page 4

Exercise

1. Measuring flow rates at outlet valves

- Screw out the plates of the outlet valves V11, V12 and V13 all the way, so that all three outlet valves are open simultaneously.
- Use the anemometer and the volume flow hood to measure the volume flow at the outlet valves V11, V12 and V13.

Note down the measurement results in the following table:

Outlet valve V11	Outlet valve V12	Outlet valve V13
Volume flow $\dot{V}_{V11}$ in ltr/s	Volume flow $\dot{V}_{V12}$ in ltr/s	Volume flow $\dot{V}_{V13}$ in ltr/s
85	41	31

Worksheet E – Two methods for determining the volume flow

Page 5

- Screw the plates back into the outlet valves V11, V12 and V13.
- Turn the plates in or out until you are measuring the same volume flow at all three outlet valves.

  Note down the measurement results as an aid:

Outlet valve V11	Outlet valve V12	Outlet valve V13
Volume flow $\dot{V}_{V11}$ in ltr/s	Volume flow $\dot{V}_{V12}$ in ltr/s	Volume flow $\dot{V}_{V13}$ in ltr/s
Adjusted, same volume flow at the exhaust valves V11, V12 and V13		
45		
Sum of the volume flow at the outlet valves V11, V12 and V13 $\dot{V}_{sum}$		
135		

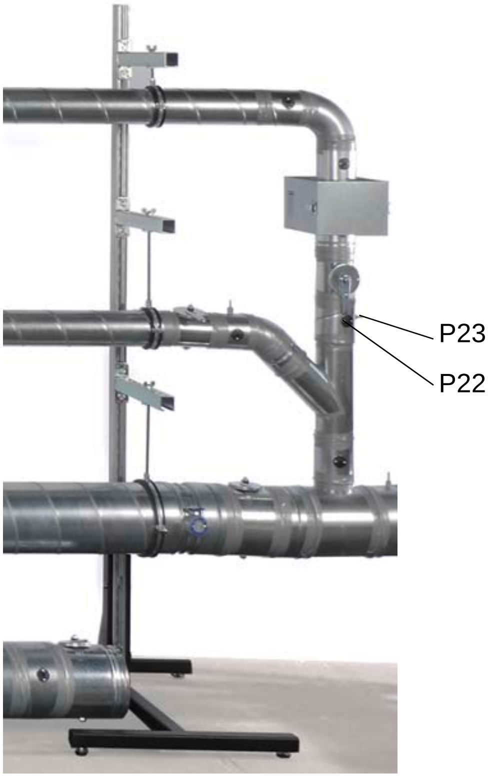
Worksheet E – Two methods for determining the volume flow

Page 6

2. Measuring dynamic pressure

- Use the digital manometer to measure the differential pressure between measuring point P22 and measuring point P23.

  This differential pressure corresponds to the dynamic pressure.



- Note down the measurement result in the table.

Measuring point 23
Dynamic pressure p_{dyn} in Pa
65

Worksheet E – Two methods for determining the volume flow

Page 7

3. Calculating volume flow

   Calculate the volume flow from the dynamic pressure at the measuring point P23.

   Your calculation result:

   $\dot{V}_{calc} = 81\,\text{ltr/s}$

   Calculation method:

$$\dot{V} = A_D \cdot \sqrt{\frac{2 \cdot p_{dyn}}{\rho}}$$

$\dot{V}$	Volume flow
A_D	Cross-section area of the pipe here: $0{,}00785\,\text{m}^2$
p_{dyn}	Dynamic pressure here: $65\,\text{Pa}$
ρ	Density of the flow medium Air: $1{,}225\,\text{kg/m}^3$ at $15\,°\text{C}$

Worksheet E – Two methods for determining the volume flow

Page 8

4. Comparing measured and calculated volume flow

   The volume flow $\dot{V}_{sum}$ you calculated in task 1 is:

   135 ltr/s

   The volume flow $\dot{V}_{calc}$ you measured in task 2 is:

   81 ltr/s

   Compare the two volume flows. Explain the different values.

   The measuring points P22 and P23 for the calculation of the volume flow $\dot{V}_{calc}$ are located just behind a branch. Here, the air flow exhibits turbulence, measurement conditions are not favourable.
   At the measurement points V11, V12 and V13 the position of the measuring points is not significant. At these measuring points volume flow is $\dot{V}_{sum}$ measured, which is not affected by turbulence.

   How could you improve the measurement of the dynamic pressure to get better results for the calculated volume flow $\dot{V}_{calc}$?

   The dynamic pressure should be measured at a measuring point, which is preceded by an approximately 1 m long calmed section. In the upper pipeline, there is no such measuring point available.

6.6 Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 1

Objective

- To measure the pressure loss of a composite 180° bend
- To calculate the resistance coefficient of the bend
- Familiarisation with an inclined tube manometer

Measuring equipment

- Inclined tube manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 112 to Page 116.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the lower pipeline is considered. The middle and upper pipelines are shut off. To do this, proceed as follows:
   – Set the throttle valves V7 and V9 to position 0 (closed).
   – Set the irises V8 and V10 to position 1 (closed).
   – Close the linear diffusers V3 and V4.
   – Close the outlet valves V11, V12 and V13.
   – Set the throttle valves V1 and V6 to position 9 (open).
   – Set the irises V2 and V5 to position 6 (open).

Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120V: max 12,5A
  230V: max 6A

4. Turn the main switch on.
5. Turn the fan switch on.

Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 4

Exercise

1. Measuring

   Set the rotation speed control knob to 100%.

   Take the following measurements:

   - Use the inclined tube manometer to measure the differential pressure between measuring points P7 and P9. This is the differential pressure across the composite 180° bend.
   - Use the anemometer to measure the flow velocity at the outlet of the lower pipeline.

   Gradually reduce the position of the rotation speed control knob and repeat the measurements.

   Note down your measurement results in the table on the following page.

Worksheet F – Pressure loss and resistance coefficient of a composite 180° bend

Page 5

2. Calculating

From the differential pressure $\Delta p_{P7\text{-}P9}$ and the flow velocity at the outlet, calculate the resistance coefficient of the composite 180° bend and enter the results into the table.

What is the relationship between flow velocity and resistance coefficient?

Rotation speed control knob	Measuring point P7 - measuring point P9	Outlet of the lower pipeline	Composite 180°-bend
in %	Differential pressure $\Delta p_{P7\text{-}P9}$ in Pa	Flow velocity v in m/s measured	Resistance coefficient ζ
100	77	16,5	0,461
80	72	16,0	0,459
60	55	14,0	0,458
50	22	8,9	0,453
40	10	5,8	0,485
35	5	4,2	0,463

Calculation method:

$$\zeta = \frac{2 \cdot \Delta p}{\rho \cdot v^2}$$

ζ Resistance coefficient
Δp Differential pressure
ρ Density of the flow medium
Air: 1,225 kg/m^3 at 15 °C
v Flow velocity

The resistance coefficient ζ is independent of the flow velocity.

6.7 Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 1

Objective

- To measure the pressure loss over a 90° bend
- To measure the volume flow
- To draw and evaluate the characteristic curve of the pressure loss over the volume flow

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 112 to Page 116.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the upper pipeline is considered. The lower and middle pipelines are shut off. To do this, proceed as follows:
   – Set the throttle valves V1, V6 and V7 to position 0 (closed).
   – Set the irises V2, V5 and V8 to position 1 (closed).
   – Close the linear diffusers V3 and V4.
   – Set the throttle valve V9 to position 9 (open).
   – Screw out the plates of the outlet valves V11, V12 and V13 a bit.

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

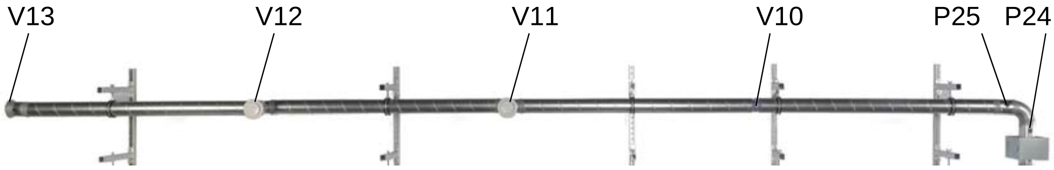
4. Turn the main switch on.
5. Turn the fan switch on.
6. Turn the rotation speed control knob to 100 %.

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 4

Exercise

1. Taking measurements



- Set the iris V10 to position 1 (closed).
- Take the following measurements:
  - Use the digital manometer to measure the differential pressure between measuring points P24 and P25. This is the differential pressure across the 90° bend.
  - Use the anemometer and the volume flow hood to measure the volume flow at the outlet valves V11, V12 and V13. Generate the sum of the three volume flows.

  Gradually change the position of the iris V10 from position 1 (closed) to position 6 (open) and repeat each of the measurements.

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

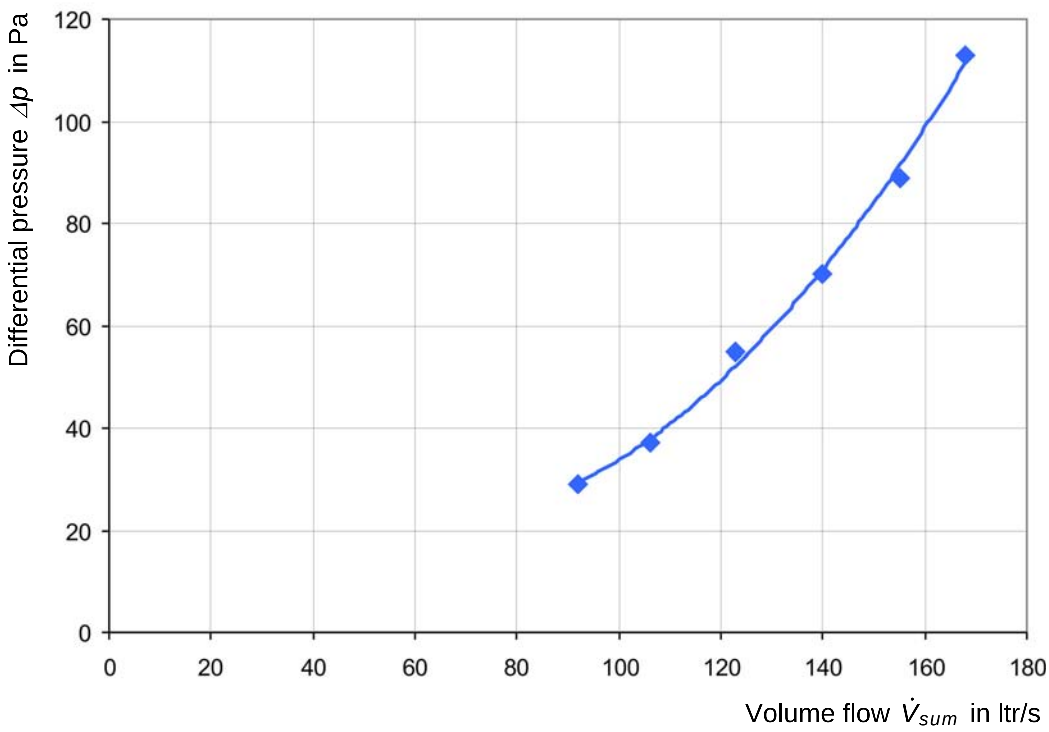
Page 5

Iris	Measuring point P24 - measuring point P25	Outlet valve V11	Outlet valve V12	Outlet valve V13	Sum V11, V12 and V13
Position	Differential pressure $\Delta p_{P24\text{-}P25}$ in Pa	Volume flow $\dot{V}_{V11}$ in ltr/s	Volume flow $\dot{V}_{V12}$ in ltr/s	Volume flow $\dot{V}_{V13}$ in ltr/s	Total volume flow $\dot{V}_{sum}$ in ltr/s
1 (closed)	29	49	24	19	92
2	37	57	28	21	106
3	55	66	32	25	123
4	70	76	36	28	140
5	89	84	40	31	155
6 (open)	113	90	44	34	168

Worksheet G – Characteristic curve of the pressure loss over a 90° bend

Page 6

2. Enter the values for the differential pressure across the total volume flow in a chart and plot the curve.



3. Evaluate the characteristics of the curve.

The differential pressure of the 90° bend increases in proportion to the square of the volume flow.

6.8 Worksheet H – Characteristic curve of the pressure loss over a filter

Page 1

Objective

- Familiarisation with throttling via iris and via rotation speed control knob
- To determine the pressure loss over a filter

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 112 to Page 116.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the middle pipeline is considered. The lower and upper pipelines are shut off. To do this, proceed as follows:
   – Set the throttle valves V1, V6 and V9 to position 0 (closed).
   – Set the irises V2, V5 and V10 to position 1 (closed).
   – Close the disc valves V11, V12 and V13.
   – Close the linear diffusers V3 and V4.
   – Install the filter element in the pocket filter F1.
   – Set the throttle valve V7 to position 9 (open).
   – Set the iris V8 to position 6 (open).

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

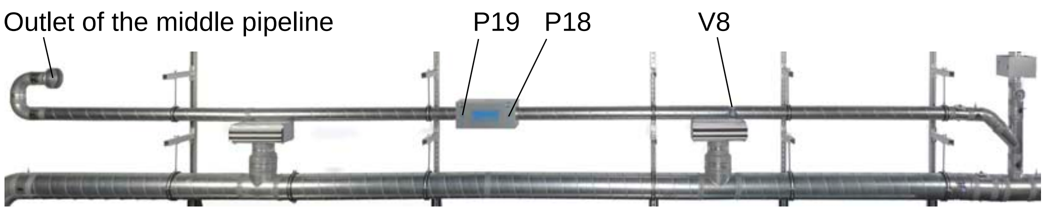
- Ensure that the following currents are complied with during continuous load:
  120V: max 12,5A
  230V: max 6A

4. Turn the main switch on.
5. Turn the fan switch on.
6. Turn the rotation speed control knob to 100%.

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 4

Exercise



1. Measurements with throttling via the iris
   - Use the digital manometer to measure the differential pressure between measuring points P19 and P18. This is the pressure loss across the filter F1.
   - Use the anemometer and the volume flow hood to measure the volume flow at the outlet of the middle pipeline.

   Gradually change the position of the iris V8 from position 6 (open) to position 1 (closed) and repeat each of the measurements.

Iris	Measuring point P19 - measuring point P18	Outlet of the middle pipeline
Position	**Differential pressure $\Delta p_{p19\text{-}p18}$ in Pa**	**Volume flow $\dot{V}$ in ltr/s**
1 (open)	96	71
2	93	69
3	86	65
4	79	61
5	69	54
6 (closed)	64	51

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 5

2. Measurements with throttling via the rotation speed control knob
   - Set the iris V8 to position 6 (open).
   - Use the digital manometer to measure the differential pressure between measuring points P19 and P18. This is the pressure loss across the filter F1.
   - Use the anemometer and the volume flow hood to measure the volume flow at the outlet of the middle pipeline.

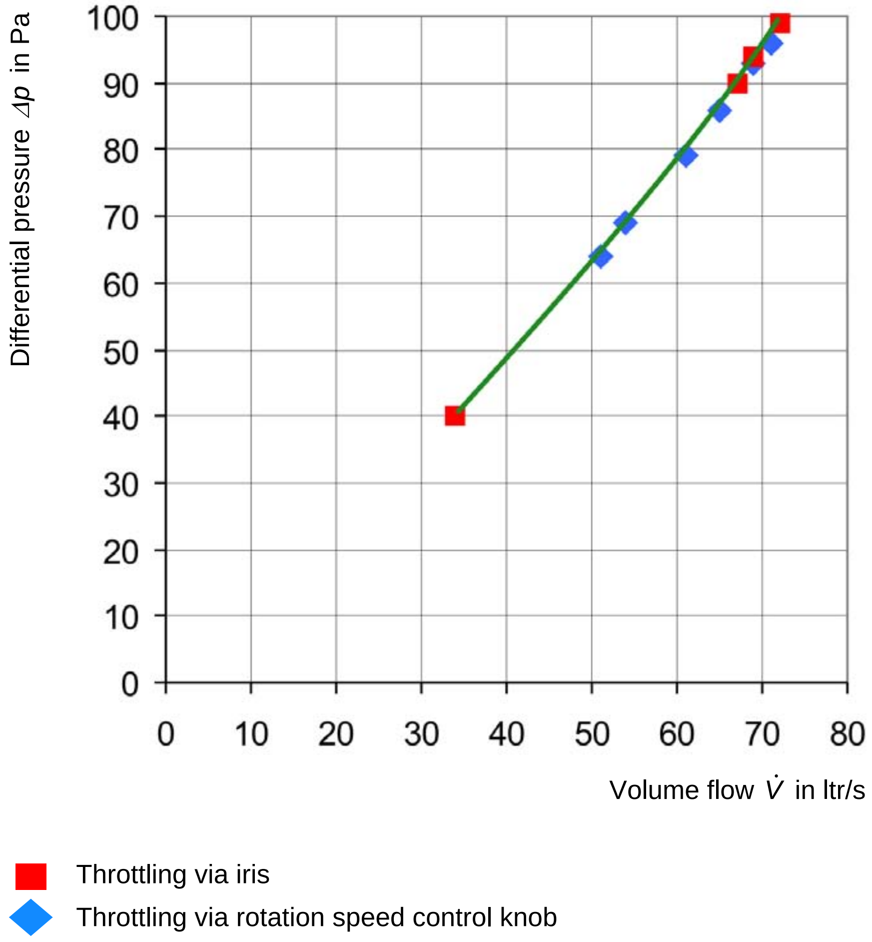
   Gradually reduce the position of the rotation speed control knob and repeat the measurements. Note down the results of your measurements in the following table.

Rotation speed control knob	Measuring point P19 - measuring point P18	Outlet of the middle pipeline
Position	Differential pressure $\Delta p_{p19\text{-}p18}$ in Pa	Volume flow $\dot{V}$ in ltr/s
100	99	72
40	94	69
35	90	67
30	40	34

Worksheet H – Characteristic curve of the pressure loss over a filter

Page 6

3. Enter the values for the differential pressure across the volume flow in a chart and plot the curve.



4. Evaluate the characteristics of the curve.

   The pressure loss of the filter increases in proportion to the volume flow.

6.9 Worksheet I – Characteristic curve of the lower pipeline

Page 1

Objective

- To measure the static pressure relative to atmospheric pressure
- To measure the volume flow
- To present and evaluate a pipeline's characteristic curve

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 112 to Page 116.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the lower pipeline is considered. The middle and upper pipelines are shut off. To do this, proceed as follows:
   – Set the throttle valves V7 and V9 to position 0 (closed).
   – Set the irises V8 and V10 to position 1 (closed).
   – Close the linear diffusers V3 and V4.
   – Close the outlet valves V11, V12 and V13.
   – Set the throttle valves V1 and V6 to position 9 (open).
   – Set the irises V2 and V5 to position 6 (open).

Worksheet I – Characteristic curve of the lower pipeline

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet I – Characteristic curve of the lower pipeline

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

4. Turn the main switch on.
5. Turn the fan switch on.

Worksheet I – Characteristic curve of the lower pipeline

Page 4

Exercise

1. Set the rotation speed control knob to 100% and take the following measurements:
   - Use the digital manometer to measure the static pressure at measuring point P3 relative to the atmospheric pressure.
   - Use the anemometer to measure the flow velocity at the outlet of the lower pipeline.

   Gradually reduce the position of the rotation speed control knob and repeat the measurements. Note down the results of your measurements in the table.

2. Calculate the volume flow from the flow velocity and enter the results into the table.

Worksheet I – Characteristic curve of the lower pipeline

Page 5

Rotation speed control knob	Measuring point P3	Outlet of the lower pipeline	
in %	Static pressure p_{P3} in Pa	Flow velocity v measured in m/s	Total volume flow $\dot{V}$ in ltr/s
100	840	10,5	330
80	800	10,0	314
60	750	9,65	303
50	690	9,23	290
45	560	8,30	261
40	261	5,05	159
35	168	3,30	104
30	122	2,50	79

Calculation method:

$$\dot{V} = A_D \cdot v$$

$\dot{V}$ Volume flow

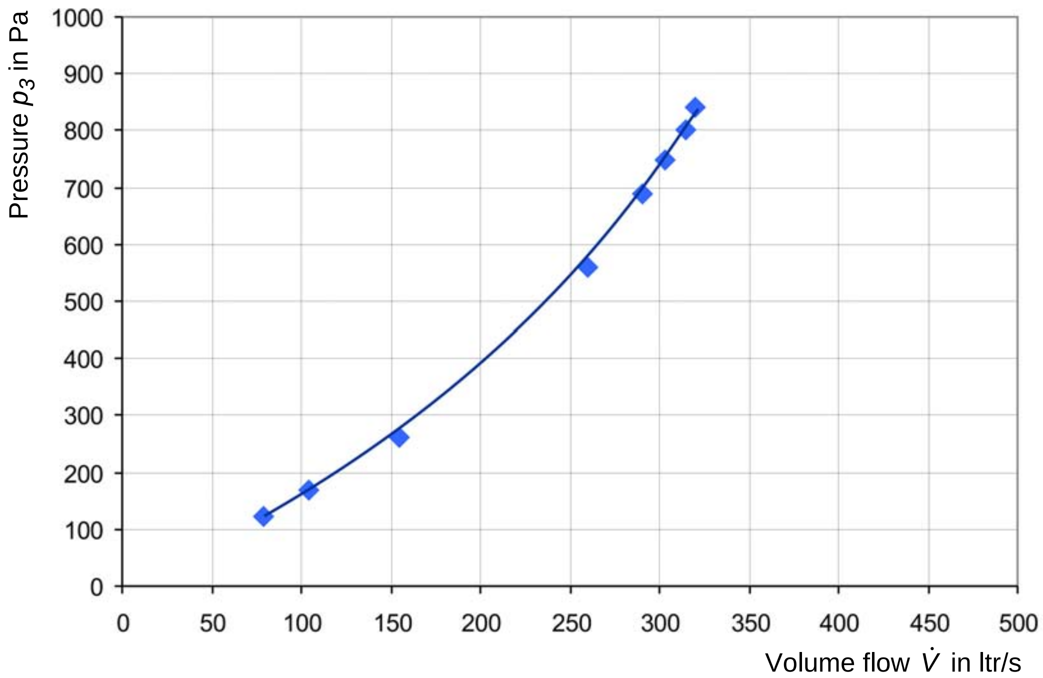
A_D Cross-section area of the pipe
here: $A_d = 0{,}03142\,\mathrm{m}^2$

v Flow velocity

Worksheet I – Characteristic curve of the lower pipeline

Page 6

3. Enter the values for the pressure across the volume flow in a chart and plot the curve.



4. Is it a system characteristic curve?

   Yes. The characteristic curve of this pipeline corresponds to the characteristic curve of the entire air duct system with these component settings.

5. Evaluate the characteristics of the curve.

   The differential pressure in the pipe increases in proportion to the square of the volume flow.

6.10 Worksheet J – Throttle characteristic curve of the lower pipeline

Page 1

Objective

- To measure the static pressure relative to atmospheric pressure
- To measure the volume flow
- To represent a throttle characteristic curve

Measuring equipment

- Digital manometer
- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 112 to Page 116.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Only the lower pipeline is considered. The middle and upper pipelines are shut off. To do this, proceed as follows:
   - Set the throttle valves V7 and V9 to position 0 (closed).
   - Set the irises V8 and V10 to position 1 (closed).
   - Close the linear diffusers V3 and V4.
   - Close the outlet valves V11, V12 and V13.
   - Set the throttle valves V1 and V6 to position 9 (open).
   - Set the irises V2 and V5 to position 6 (open).

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

4. Turn the main switch on.
5. Turn the fan switch on.

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 4

Exercise

1. Measurements

   Set the rotation speed control knob to 100% and take the following measurements:

   - Use the digital manometer to measure static pressure at measuring point P3 relative to the atmospheric pressure.
   - Use the anemometer to measure the flow velocity at the outlet of the lower pipeline.

   Gradually change the position of the throttle valve V6 from position 9 (open) to position 0 (closed) and repeat each of the measurements.

   Enter the measured values in the table.

2. Calculations

   Calculate the volume flow from the flow velocity at the outlet and enter the results into the table.

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 5

Throttle valve	Measuring point P3	Outlet of the lower pipeline	
Position	Static pressure p_{P3} in Pa	Flow velocity v measured in m/s	Total volume flow $\dot{V}$ in ltr/s
9 (open)	200	15,3	481
8	260	15,0	471
7	350	14,3	449
6	450	13,7	430
5	620	12,2	383
4	775	8,8	276
3	875	4,5	141
2	909	3,0	94
1	915	1,9	60
0 (closed)	918	1,5	47

Calculation method:

$$\dot{V} = A_D \cdot v$$

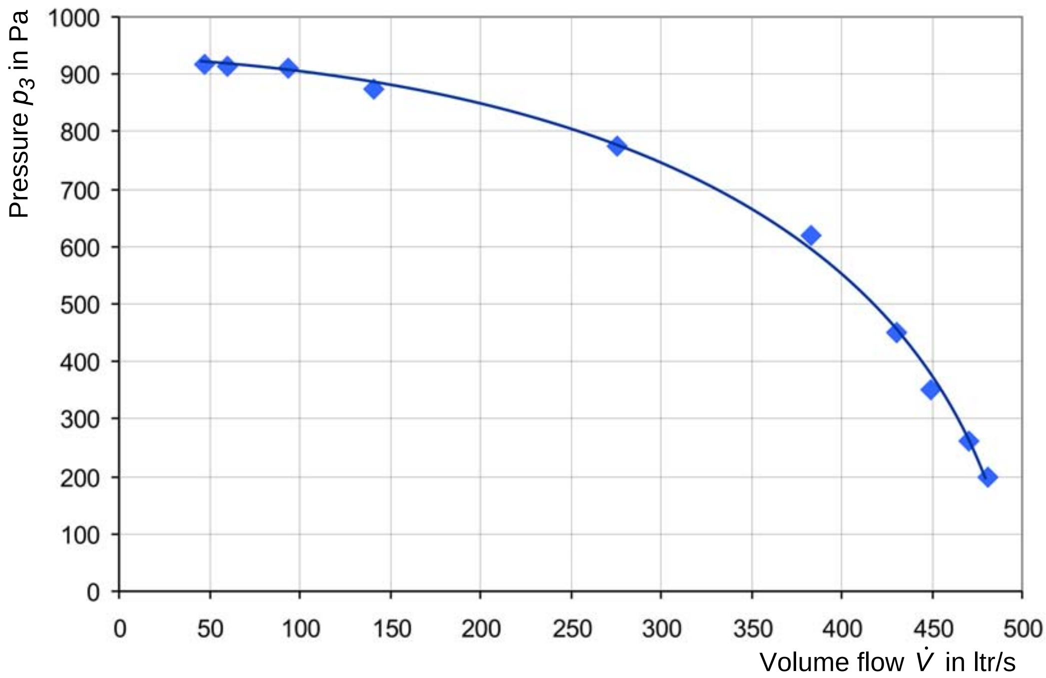
$\dot{V}$ Volume flow
A_D Cross-section area of the pipe
here: $A_d = 0{,}03142\,m^2$
v Flow velocity

Worksheet J – Throttle characteristic curve of the lower pipeline

Page 6

3. Characteristic curve

   - Enter the values for the pressure across the volume flow in a chart and plot the curve.



4. Comparison

   Compare the characteristic curve from Chapter 6.9, Page 155 (Worksheet I – Characteristic curve of the lower pipeline) with the characteristic curve on this page (Worksheet J – Throttle characteristic curve of the lower pipeline).

   What do the characteristic curves represent?

   The throttle curve shown here is part of the fan characteristic curve,

   whereas Chapter 6.9 shows a system characteristic curve.

   The intersection of the two curves is the operating point.

6.11 Worksheet K – Air distribution in the air duct system

Page 1

Objective

- To operate upper, middle and lower pipelines individually and in combination with each other
- To measure the volume flows at outlet valves
- To evaluate the air distribution

Measuring equipment

- Anemometer

Preparation for the experiment

1. Assemble the experiment setup according to Page 112 to Page 116.

⚠ CAUTION

Sharp edges on the pipes.

Risk of hand injuries.

- Wear gloves.

2. Create the starting state. To do this, proceed as follows:
   - Set the throttle valve V6 to position 9 (open).
   - Set the irises V2, V5, V8 and V10 to position 6 (open).
   - Close the linear diffusers V3 and V4.

Worksheet K – Air distribution in the air duct system

Page 2

3. Observe the following safety precautions.

⚠ WARNING

Noise emission > 70 dB(A).

Risk of hearing damage.

- Wear ear defenders.

⚠ WARNING

Strong blow out force at the fan outlet and rotating parts in the fan outlet.

Risk of hand injuries.

- Do not reach into the fan outlet.
- Only operate the fan when a pipe is mounted on the fan outlet.

⚠ CAUTION

Strong suction force at the fan inlet.

Items and clothing may be drawn in.

- Do not stand near the fan inlet.
- Do not store loose items where they can be drawn in by the fan.

Worksheet K – Air distribution in the air duct system

Page 3

NOTICE

Overload of the electrics.

Risk of damage to the electrics.

- Ensure that the following currents are complied with during continuous load:
  120 V: max 12,5 A
  230 V: max 6 A

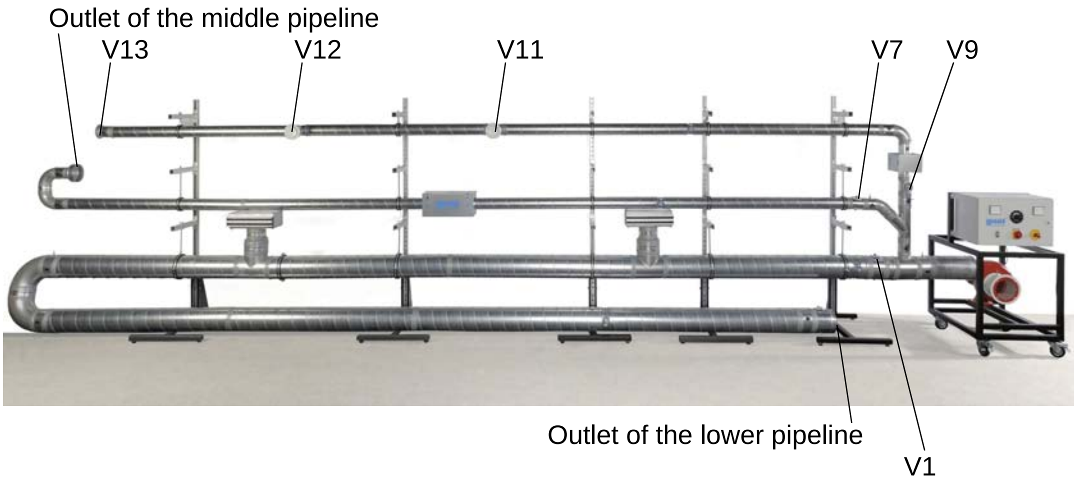
---

4. Turn the main switch on.
5. Turn the fan switch on.
6. Turn the rotation speed control knob to 100 %.

Worksheet K – Air distribution in the air duct system

Page 4

Exercise



1. Opening or blocking individual pipelines

   From the table on the next page, select the desired settings and open or block the individual pipelines accordingly.

   - To open the upper pipeline:
     Set the throttle valve V9 to position 9 (open).
   - To block the upper pipeline:
     Set the throttle valve V9 to position 0 (closed).
   - To open the middle pipeline:
     Set the throttle valve V7 to position 9 (open).
   - To block the middle pipeline:
     Set the throttle valve V7 to position 0 (closed).
   - To open the lower pipeline:
     Set the throttle valve V1 to position 9 (open).
   - To block the lower pipeline:
     Set the throttle valve V1 to position 0 (closed).

Worksheet K – Air distribution in the air duct system

Page 5

2. Measurements

Use the anemometer and the volume flow hood to measure the volume flows at

- the outlet valves V11, V12 and V13
- the outlet of the middle pipeline
- the outlet of the lower pipeline

As the throttle valves do not fully seal the flow cross-section, the measurements must always be taken at all outlet valves and pipe outlets.

Note down the results of your measurements in the table.

Upper pipeline	Middle pipeline	Lower pipeline	Upper pipeline				Middle pipeline	Lower pipeline	Sum of all pipelines
			V11	V12	V13	Sum V11, V12 and V13	Outlet	Outlet	
			Volume flow $\dot{V}$ in ltr/s						
open	open	open	24	12	9	45	45	440	530
open	open	closed	51	25	19	95	85	44	224
open	closed	open	24	12	9	45	20	455	520
open	closed	closed	67	33	25	125	20	44	189
closed	open	open	16	8	6	30	45	445	520
closed	open	closed	16	8	6	30	110	44	184
closed	closed	open	16	8	6	30	20	480	530
closed	closed	closed	16	8	6	30	20	44	94

white: closed
yellow: open

Worksheet K – Air distribution in the air duct system

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3. Evaluate the measurement results.

If the pipelines are opened ***individually***, the lower pipeline will show the largest volume flow with 480 ltr/s. This is due to the large nominal diameter of 200 mm and thus the large cross-section area of 0,0314 m^2.
In addition, the middle and upper pipeline are connected to the fan outlet by a 90° branch. This branch represents a high flow resistance and thus leads to lower volume flows in the middle and upper pipeline.
If the middle and/or upper pipelines are operated individually, the volume flows there will be 110 ltr/s and 125 ltr/s. Both pipelines have nominal diameters of 100 mm and cross-section areas of 0,00785 m^2.
However, the upper pipeline has more outlets than the middle pipeline.

If the pipelines are opened ***in combination*** with each other, then the largest volume (440...455 ltr/s) will be detected in the lower pipeline, if it has been opened. This volume flow is only slightly dependent on whether one or both of the other pipelines are open.
If only the upper and middle pipeline, each DN 100, are open then the volume flows are more evenly distributed (95 ltr/s or 85 ltr/s).

7 Appendix

7.1 Technical data

Dimensions

Length x Width x Height (fan stand)	1700 mm x 650 mm x 1400 mm
Weight	approx. 70 kg

Connection values

Electric power supply	230 V, 50 Hz, 1 phase
Nominal consumption (output)	1 kW

Alternatives optional, see rating plate

Fan

Manufacturer	Elektror	
Type	E064	
Motor	Electric motor	
Volume flow	Maximum	approx. 28 m^3/min
Differential pressure	Maximum	approx. 1000 Pa

Filter matting

Manufacturer	Systemair
Type	FGR
Filter class	G3

Pocket filter

Manufacturer	Systemair
Type	FFR
Filter class	G3

Outlet valves

Type	Disc valve
Nominal size	DN 100

Inclined tube manometer

Manufacturer	Electro Mation	
Type	MG 20	
Measuring range		0...200 Pa

Digital manometer

Manufacturer	Brigon	
Type	PM 6530	
Measuring range		0...20.000 Pa
Measurement accuracy	±0,3% of measuring range final value	
Electrical power supply		Block battery, 9 V

Anemometer

Manufacturer	Airflow Lufttechnik	
Type	LCA 301	
Measuring range for flow velocity		0,25...30 m/s
Measurement accuracy for flow velocity		± 1 %
Measuring range for volume flow (calculated from flow velocity and cross-section area)		1...999999 ltr/s
Volume flow hood		
Rectangular measurement area		240 mm x 290 mm
Circular measurement area		Diameter 200 mm
Electrical power supply		Block battery, 9 V

Ammeter

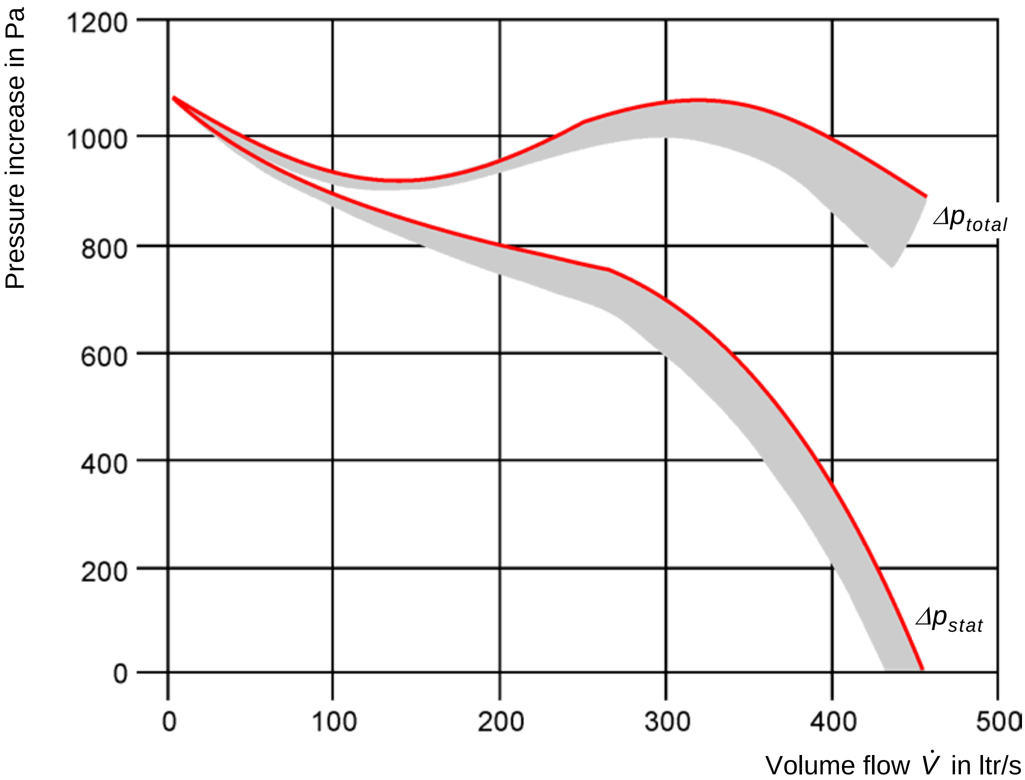
Measuring range		0...10 A
Accuracy class	2,5	

Voltage meter

Measuring range		0...230 V
Accuracy class	2,5	

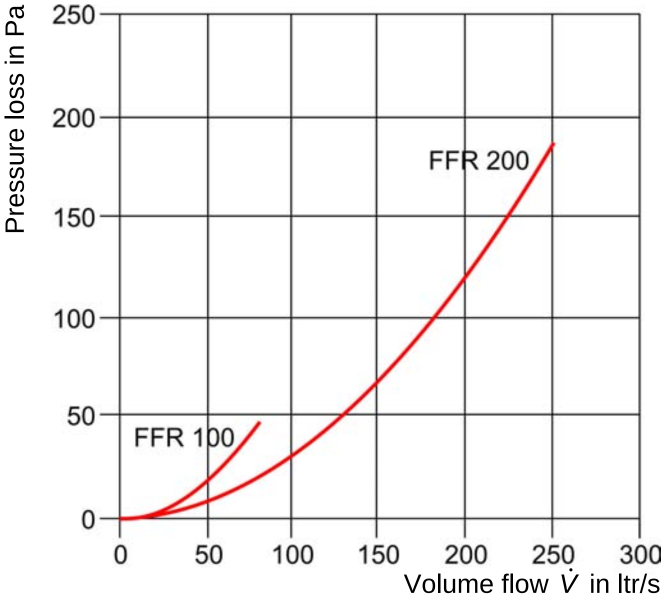
7.2 Characteristic curves

Fan characteristic curve



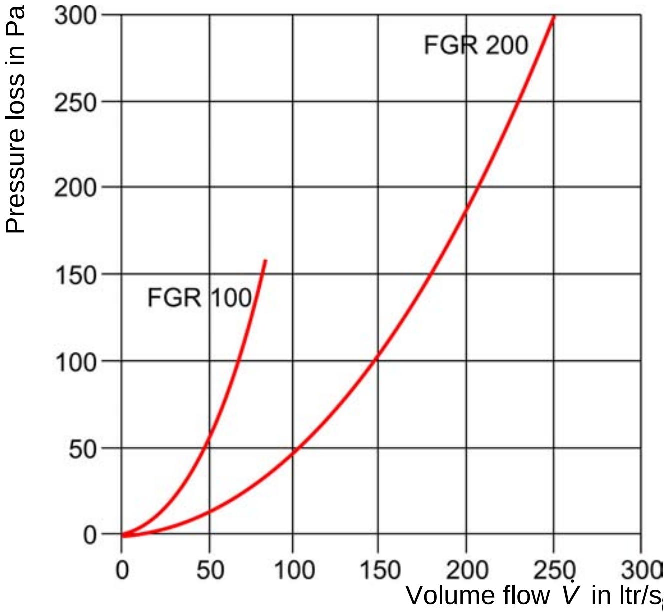
Characteristic curve of the pocket filter elements

- FFR 100 (DN 100, filter class G3)
- FFR 200 (DN 200, filter class G3)



Characteristic curve of the filter matting

- FGR 100 (DN 100, filter class G3)
- FGR 200 (DN 200, filter class G3)



7.3 List of formula symbols and units

Formula symbols	Mathematical/physical value	Unit
A_D	Cross-section area of the pipe	mm^2
A_p	Cross-section area on the pressure side of the fan	
A_s	Cross-section area on the suction side of the fan	
I	Current	A
n	Speed	1/min
p	Pressure	bar, mbar, Pa, kPa
p_{dyn}	Dynamic pressure	
p_p	Pressure on the pressure side of the fan	
p_s	Pressure on the suction side of the fan	
p_{stat}	Static pressure	
p_{total}	Total pressure	
P	Power	W
P_{el}	Electrical power	
P_{hydr}	Hydraulic power	
R	Flow resistance	$Pa \cdot \frac{s}{m^3}$
U	Electric voltage	V
v	Flow velocity	m/s
$\dot{V}$	Volume flow	ltr/s, ltr/min, ltr/h, m^3/min, m^3/h
$\dot{V}_{calc}$	Calculated volume flow	
$\dot{V}_{meas}$	Measured volume flow	
Δp	Differential pressure	bar, mbar, Pa, kPa
η	Efficiency	%
ρ	Density of the flow medium	kg/m^3
ζ	Resistance coefficient	–

7.4 Conversion tables

Unit	mm^3	cm^3	ltr	m^3
1 mm^3	1	0,.001	0,000001	0,000000001
1 cm^3	1.000	1	0,001	0,000001
1 ltr	1.000.000	1.000	1	0,001
1 m^3	1.000.000.000	1.000.000	1.000	1

Tab. 7.1 Conversion table for units of volume

Unit	ltr/s	ltr/min	ltr/h	m^3/min	m^3/h
1 ltr/s	1	60	3600	0,06	3,6
1 ltr/min	0,01667	1	60	0,001	0,06
1 ltr/h	0,000278	0,01667	1	0,00001667	0,001
1 m^3/min	16,667	1000	0,0006	1	60
1 m^3/h	0,278	16,667	1000	0,01667	1

Tab. 7.2 Conversion table for units of volume flow

Unit	bar	mbar	Pa	kPa
1 bar	1	1000	100000	100
1 mbar	0,001	1	100	0,1
1 Pa	0,00001	0,01	1	0,001
1 kPa	0,01	10	1000	1

Tab. 7.3 Conversion table for units of pressure

7.5 Scope of delivery

HL 710 Air Duct Systems

Experiment Instructions for HL 710 Air Duct Systems