Overview of Section 2
Vacuum Knowledge

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Seminars and training
Schmalz offers customized training, seminars and courses at the Schmalz Academy. Customers benefit from our comprehensive expertise and all our years of experience as vacuum specialists. You will find more details in the chapter “Services”.
Overview of a Vacuum System

Vacuum systems are used as grippers in automated applications. Customers benefit from the comprehensive component program of Schmalz, the vacuum specialist, when designing a vacuum system.

Vacuum generators
Centralized or decentralized vacuum generation by means of ejectors, pumps or blowers

Filters and connectors
Filters protect the vacuum generator; hoses and connectors connect the components

Switches and system monitoring
Measuring and control components ensure safe operation of the vacuum system

Mounting elements
Fast and flexible connection of vacuum components to tooling systems

Valve technology
Valves are used to control the vacuum as well as the compressed air (decentralized or centralized)

Vacuum gripping systems
Complete solutions, such as large-area gripping systems, layer grippers or vacuum spiders, are customized to meet customer needs
Vacuum suction pads are the link between the workpiece and the handling system. They consist of the suction pad (elastomer part) and a connecting element.

Suction pads are used to grip and move workpieces in a plant or on a robot. A suction pad does not attach itself to the surface of a workpiece. Instead, the ambient air pressure (atmospheric pressure) presses the suction pad against the workpiece as soon as the ambient pressure is greater than the pressure between the suction pad and the workpiece.

This pressure difference is achieved by connecting the suction pad to a vacuum generator, which evacuates the air from the space between the pad and the workpiece. If the suction pad is in contact with the surface of the workpiece, no air can enter it from the sides and a vacuum is generated.

The holding force of the suction pads increases proportionally with the difference between the ambient pressure and the pressure inside the pad.

The holding force of a suction pad is calculated with the formula:

\[ F = \Delta p \times A \]

\( F \) = Holding force
\( \Delta p \) = Difference between ambient pressure and pressure of the system
\( A \) = Effective suction area (the effective area of a suction pad under vacuum)

This means the holding force is proportional to the pressure difference and the suction area. The greater the difference between ambient pressure and pressure in the suction pad or the larger the effective suction area, the greater the holding force. The force can vary depending on a change of the pressure difference and area parameters.

Suction Pad Shapes

Suction pads from Schmalz can be divided into universal suction pads and suction pads for special applications. Universal suction pads cover a wide range of requirements. Suction pads for special applications were developed to meet the requirements of individual industries. They may be characterized by special properties, such as the handling of thin-walled and greasy body panels in the sheet metal industry or of porous and structured workpieces in the wood industry.
The following shapes are generally distinguished:
• Flat suction pads
• Bellows suction pads

Each suction pad shape offers advantages that are reinforced and optimized by the combination with a suitable material. The available suction pad materials are described in detail in the section “Suction pad materials”.

**Flat Suction Pads**
Flat suction pads are particularly suited for handling workpieces with flat or slightly curved surfaces. Flat suction pads can be evacuated quickly due to their flat shape and low inner volume, therefore they can grip the workpiece in a very short time and can withstand the forces which result from fast movement of the object during handling.

**Advantages of flat suction pads**
• Large variety of different suction pad materials and shapes (round, oval, steep or flat leveling sealing lip)
• Flat shape and low inner volume result in minimum evacuation times
• Good stability of the suction pad allows for high shear forces and positioning accuracy while workpieces are picked up

**Typical areas of application**
• Handling of smooth to lightly rough workpieces, such as sheet metal plates, cardboard, glass plates, plastic parts and wooden boards
• In automated processes with short cycle times

**Bellows Suction Pads**
Bellows suction pads are used when it is necessary to compensate for varying workpiece heights, to handle parts with uneven surfaces or fragile parts. The bellows make this suction pad especially flexible and adaptable.

**Advantages of bellows suction pads**
• Good adaptation to uneven surfaces
• Lift effect while picking up
• Compensation of differences in height
• Fragile workpieces are picked up gently

**Typical areas of application**
• Handling of curved or uneven workpieces, such as body panels, tubes, cardboard, etc.
• Handling of fragile workpieces, such as electronic components, injection molded plastic parts, etc.
• Handling of non-rigid or flexible workpieces, such as packaged or shrink wrapped products

Both types of suction pads are available in a wide range of shapes and sizes. You will find more information on basic data and applications for the individual series in the chapter “Vacuum Suction Pads”.

**Suction Pad Materials**
Application and ambient conditions are important for the selection of the right suction pad and the appropriate material. Abrasion resistance, oil resistance and food safety are often required of a suction pad. These requirements can be met by selecting the appropriate material.

Schmalz develops its suction pad materials in-house with new materials being developed, tested and optimized in our own Plastics Competence Center.
# Material Overview

<table>
<thead>
<tr>
<th>Description</th>
<th>NBR</th>
<th>NBR-AS</th>
<th>SI</th>
<th>SI-AS</th>
<th>NK</th>
<th>HT1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chemical designation / trade name</strong></td>
<td>Nitrile caoutchuc (AS = antistatic)</td>
<td>Silicone caoutchuc (AS = antistatic)</td>
<td>Natural rubber</td>
<td>High temperature material</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Color / coding</strong></td>
<td>black, gray, blue, light blue</td>
<td>black with blue dot</td>
<td>white (trans-lucid), green</td>
<td>black with red dot</td>
<td>gray, light brown, black</td>
<td>blue</td>
</tr>
<tr>
<td><strong>Chemical resistance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General weathering resistance</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>Ozone resistance</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>Oil resistance</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>Fuel resistance</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>Alcohol resistance, ethanol 96%</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>Solvents resistance</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>General resistance to acids</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>Steam resistance</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td><strong>Mechanical characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wear resistance</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>Resistance to permanent deformation</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
<td>⚫</td>
</tr>
<tr>
<td>Specific resistance in [Ω x cm]</td>
<td>–</td>
<td>≤ 10²</td>
<td>–</td>
<td>≤ 10²</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Shore hardness to DIN ISO 7619</td>
<td>40 to 90 ± 5</td>
<td>55 ± 5</td>
<td>30 to 85 ± 5</td>
<td>55 ± 5</td>
<td>30 to 90 ± 5</td>
<td>60 ± 5</td>
</tr>
<tr>
<td><strong>Temperature resistance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-term in °C (&lt; 30 sec.)</td>
<td>-30° to +120°</td>
<td>-30° to +120°</td>
<td>-50° to +220°</td>
<td>-35° to +220°</td>
<td>-35° to +120°</td>
<td>-25° to +170°</td>
</tr>
<tr>
<td>Longer-term in °C</td>
<td>-10° to +70°</td>
<td>-10° to +70°</td>
<td>-30° to +180°</td>
<td>-20° to +180°</td>
<td>-25° to +80°</td>
<td>-10° to +140°</td>
</tr>
<tr>
<td><strong>Target industry</strong></td>
<td>Universal</td>
<td>Universal</td>
<td>Packaging, CD/DVD</td>
<td>Packaging, CD/DVD, Electronics</td>
<td>Wood, Packaging</td>
<td>Plastics, Glass</td>
</tr>
<tr>
<td><strong>Further characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food grade according to CFR 21 §177.2600 FDA</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaving few marks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Absence of PWIS (paint-wetting impairment substances)</td>
<td>NBR-60, NBR-45</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

- Approximate value: depends on ambient temperature, application force, recovery time and wall thickness of suction pad
- After-bake of silicone 4 h/200 °C = ~+5 Shore A
- With slight oil wetting
- Varies, for technical reasons, for foam rubber

Exellent: ⚫⚫⚫⚫ Very good: ⚫⚫⚫ Good: ⚫ Poor to satisfactory: ⚫
# Vacuum Knowledge

The Vacuum System and its Components

## Material Overview

<table>
<thead>
<tr>
<th>ED</th>
<th>PU</th>
<th>VU1</th>
<th>PVC</th>
<th>FPM</th>
<th>CR</th>
<th>EPDM</th>
<th>EPDM-MOS</th>
<th>ECO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastodur</td>
<td>Polyurethane</td>
<td>Vulkollan</td>
<td>Polyvinyl chloride</td>
<td>Fluorocautchuc</td>
<td>Chloroprene</td>
<td>Ethylene-propylene-caoutchuc</td>
<td>Foam rubber made of Ethylene-propylene-caoutchuc</td>
<td>Epichlor</td>
</tr>
<tr>
<td>green, blue</td>
<td>blue, dark green</td>
<td>dark green</td>
<td>blue (translucid)</td>
<td>black with white dot</td>
<td>black, gray</td>
<td>black, gray</td>
<td>black, gray</td>
<td>black</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Color</th>
<th>Properties</th>
<th>Temperature Range</th>
<th>Compatibility</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ED-85</td>
<td></td>
<td></td>
<td>-40° to +100°</td>
<td>Metal, Wood</td>
<td>✔</td>
</tr>
<tr>
<td>ED-60</td>
<td></td>
<td></td>
<td>-40° to +130°</td>
<td>Metal, Wood</td>
<td></td>
</tr>
</tbody>
</table>
Storage and Cleaning of Suction Pads

Observe the following information regarding storage and cleaning for the sensitive elastomer part of the suction pad:

Store suction pads in a cool place (between 0 °C and 15 °C, max. 25 °C) that is dark, dry, low in dust and offers protection from the weather, ozone and drafts, as well as stress. The effects of ozone, light (especially UV), heat, oxygen, humidity, as well as mechanical influences, can reduce the service life of the suction pad.

Clean suction pads with soap and warm water, and dry them at room temperature.

Technical Data of Suction Pads

Certain calculations are required for the selection of individual components when designing a vacuum system. The specified values are based on a vacuum level of -0.6 bar as well as a dry or lubricated workpiece surface. They are given without a safety factor. Depending on the operating conditions, one should keep in mind reductions that may occur due to friction or if a vacuum level is not reached (e.g. due to porous workpieces).

The most important technical data of the suction pads are explained below.

<table>
<thead>
<tr>
<th>Theoretical suction force</th>
<th>Shear force</th>
<th>Inner volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_{th} )</td>
<td>( F_{r} )</td>
<td>( F_{g} )</td>
</tr>
</tbody>
</table>

The theoretical suction force is the force acting perpendicular to the surface. The specifications in the catalog are calculated values in newtons.

The shear force is the force acting tangentially to the surface. The specifications in the catalog are measured values in newtons.

The inner volume indicates the volume of a body that has to be evacuated to pick up a workpiece. It is used to determine the total volume of the gripper system and is included when calculating evacuation times.
The design of the suction pad always depends on the actual application. For this reason, various physical values must be calculated and determined before the correct suction pad can be selected.

Later in this chapter, the design of a vacuum system is described in more detail based on a calculation example.

Friction coefficient

The friction coefficient μ describes the relationship between friction force and normal force. It is not possible to specify generally valid values of the friction coefficient between the suction pad and the workpiece. It has to be determined correctly through trials with the condition of the workpiece surface (rough/dry/moist/oily) or the properties of the suction pad (shape/sealing lip/sealing edge/suction pad material/Shore hardness) having a major influence.

Calculation of the holding forces

The calculation of holding forces can only be about theoretical values. In practical applications, many factors, such as the size and shape of the suction pad, the surface finish and the rigidity of the workpiece (deformation) play a decisive role. That is the reason why we recommend a safety factor (S) of at least 2. The German accident prevention regulation, UVV, prescribes a binding safety factor of 1.5. When swiveling workpieces during the handling task, a safety factor of 2.5 or higher has to be used, in order to cope with the resulting turning forces.

The holding force of a suction pad is the product of:

\[ F = \Delta p \times A \]

- \( F \) = Holding force (without safety factor, purely static)
- \( \Delta p \) = Difference between ambient pressure and pressure of the system
- \( A \) = Effective suction area (the effective area of a suction pad under vacuum)
Diameter of the suction pad
The holding force of a suction pad depends on its effective diameter. The condition of the workpiece and the number of suction pads are also crucial for the holding force that a vacuum system can generate.

The required diameter can be determined with the aid of the following formula:

For horizontal pick-up:
\[ d = 1.12 \times \sqrt{\frac{m \times S}{P_U \times n}} \]

For vertical pick-up:
\[ d = 1.12 \times \sqrt{\frac{m \times S}{P_U \times n \times \mu}} \]

- \( d = \) Suction pad diameter in cm (with double lip ≈ internal diameter, with bellows suction pad = inner diameter of sealing lip)
- \( m = \) Weight of the workpiece in kg
- \( P_U = \) Vacuum in bar
- \( n = \) Number of suction pads
- \( \mu = \) Friction coefficient
- \( S = \) Safety factor

Calculation example for horizontal pick-up:
\[ d = 1.12 \times \sqrt{\frac{50 \text{ kg} \times 2}{0.4 \text{ bar} \times 4}} \]
\[ d = 8.85 \text{ cm} \]

A sensible selection is the suction pad PFYN 95 with a nominal diameter of 95 mm.

Calculation example for vertical pick-up:
\[ d = 1.12 \times \sqrt{\frac{50 \text{ kg} \times 2}{0.4 \text{ bar} \times 4 \times 0.5}} \]
\[ d = 12.5 \text{ cm} \]

A sensible selection is the suction pad PFYN 150 with a nominal diameter of 150 mm.

Suction rate or required volume flow \([\text{\text{\{}\text{\text{\{}\text{\text{\}}}}}]\]
The volume flow that generates the vacuum is important for the suction force. The workpiece material is the principal factor for the required volume flow.

The table shows typical values for the volume flow or suction rate depending on the diameter of the suction pad with smooth and air-tight surface.

<table>
<thead>
<tr>
<th>Suction pad Ø</th>
<th>Suction area A [cm²]</th>
<th>Volume flow [m³/h]</th>
<th>Volume flow [l/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 60 mm</td>
<td>28</td>
<td>0.5</td>
<td>8.3</td>
</tr>
<tr>
<td>up to 120 mm</td>
<td>113</td>
<td>1.0</td>
<td>16.6</td>
</tr>
<tr>
<td>up to 215 mm</td>
<td>363</td>
<td>2.0</td>
<td>33.3</td>
</tr>
<tr>
<td>up to 450 mm</td>
<td>1,540</td>
<td>4.0</td>
<td>66.6</td>
</tr>
</tbody>
</table>

Important:
Conduct suction trials for porous parts.
Special grippers are used in applications in which regular suction pads cannot be used. Special grippers are used to handle wafers, films, paper, fragile workpieces or textile fiber composites. They serve as a connection element between the workpiece and the handling system just like the suction pad.

Schmalz separates special grippers into the following series:

- Floating suction pads
- Wafer grippers
- Magnetic grippers
- Composite grippers
- Needle grippers

Floating suction pads are pneumatically operated special grippers with integrated vacuum generation. They operate on the Bernoulli principle and work as a low-contact system. The workpiece “floats” on an air cushion at the gripper surface. This makes the floating suction pad ideally suited for the handling of very sensitive products. The high volume flow can compensate for leakage, when handling porous workpieces.

**Advantages of floating suction pads:**

- Low-contact handling
- High volume flow
- Safe separation of thin, porous workpieces
- Integrated vacuum generation

**Typical areas of application:**

- Handling of fiber composites, paper, film, wood veneer, printed circuit boards, wafers and solar cells
- Separation of thin, porous workpieces
Vacuum Knowledge

The Vacuum System and its Components

Magnetic Grippers

Magnetic grippers provide safe gripping of ferromagnetic workpieces by using the magnetic field of an integrated permanent magnet. The magnet is moved with compressed air to activate and deactivate gripping. Magnetic grippers are operated with pneumatic valves. The gripper does not require a voltage source for this purpose.

Advantages of magnetic grippers:
- Safe gripping with a permanent magnet is possible without voltage source
- Control of permanent magnet with compressed air and vacuum

Typical areas of application:
- Handling of ferromagnetic workpieces
- Handling of blanks and perforated plates as well as sheet metal parts with drilled holes/breakouts or complex shapes
- Support of vacuum gripping system in highly dynamic handling of sheet metal parts

Needle Grippers

The needles are pressed into the workpiece and herewith the gripping process is realized. The needles are ejected pneumatically. The needles are extended at an angle to ensure reliable gripping of the workpieces. Once the gripping process is complete, the needles are retracted either through spring force or pneumatically.

Advantages of needle grippers:
- Safe handling of non-rigid materials or materials with an unstable shape
- Different shapes for unique operating conditions
- Selectable needle diameters and adjustable strokes

Typical areas of application:
- Handling of porous and/or non-rigid workpieces, such as textiles, insulating and foam materials, fiber composites such as carbon and glass fiber, fleece or felts, carpets, filters, fabric, styrofoam as well as metal foams
Vacuum Knowledge

The Vacuum System and its Components

Wafer Grippers

Wafer grippers are ideally suited for the handling of sensitive parts, especially photovoltaic components such as wafers and cells. The wafer gripper is equipped with an integrated vacuum generator. The high volume flow and the moderate vacuum level allow gentle handling of workpieces.

Advantages of wafer grippers:
• Extremely fast and accurate handling; implements cycle times of less than one second
• High volume flow with low air consumption
• Integrated vacuum generation, including blow-off function
• Many accessories for perfect matching to different process steps in photovoltaics industry

Typical areas of application:
• Handling of photovoltaics components also under cleanroom conditions
• Handling of fragile workpieces
• Handling of porous, permeable workpieces

Composite Grippers

Composite grippers are mainly used for handling fragile workpieces. They are operated pneumatically and have an integrated vacuum generator.

Due to their high volume flow and the moderate vacuum level, composite grippers are ideally suited for handling fragile components.

Advantages of composite grippers:
• Secure gripping, even with porous materials or partial coverage
• Short cycle times and accurate positioning
• Integrated vacuum generation, including blow-off function
• High volume flow

Typical areas of application:
• Handling of fiber composites, such as carbon fiber reinforced composites
• Handling of electrodes, separators and battery cells
• Handling of extremely thin, sensitive components
• Handling of porous, permeable workpieces
• Handling of blank circuit boards
Mounting Elements

Schmalz offers a broad product range of mounting elements to integrate grippers (suction pads or special grippers) into gripping systems.

The following mounting elements can basically be distinguished:

• Vacuum end effectors
• Sections, crossbeams and connectors
• Holders and adapters
• Spring plunger
• Jointed mountings

Products from Schmalz are listed in the chapter “Mounting Elements”.

Vacuum End Effectors
The Schmalz modular system for vacuum end effectors (VEE) allows fast, flexible configuration of end effectors for different processes.

A wide selection of combinations of vacuum feed and zones, connection elements and suction pad connections is available to create the matching end effector.

Vacuum end effectors can be combined with many suction pads from the Schmalz product range (see chapter “Vacuum Suction Pads”).
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The Vacuum System and its Components

Sections, crossbeams and connectors
These elements are used to build the basic structure of a vacuum gripping system. To reduce the number of hoses, you can build the sections as vacuum distributors with end covers and sealing frames.

Holdes and adapters
The suction pads are attached to the basic structure or the traverse with holders and adapters. Different types of aluminum sections or square and round tubes are available.

Spring plungers
Spring plungers are used to compensate height differences of workpieces. They also cushion the impact of the suction pad and allow handling of fragile workpieces.

Jointed mountings
Jointed mountings provide a better adaption of the suction pad to the workpiece due to the design of Flexolink FLK and ball joint KGL that can be swiveled in all directions.

Suction pads
(chapter “Vacuum Suction Pads” or “Special Grippers”)
Vacuum Knowledge

The Vacuum System and its Components

Vacuum Generators

Vacuum generators provide the vacuum level that is required for the handling task. The vacuum is created either pneumatically or electrically.

Pneumatic vacuum generators implement short cycle times and can be integrated directly into the system due to their compact and lightweight design.

Electrical vacuum generators are used in applications when compressed air is not available or when very high suction capacities are required.

**Pneumatic vacuum generators**
- Ejectors

**Electrical vacuum generators**
- Pumps
- Vacuum Blowers

**Important:**
The nominal suction rate of all vacuum generators is given in l/min or m³/h. The values are based on an ambient pressure of 1,013 mbar (sea level) and an ambient temperature of 20 °C.

The maximum suction rate therefore indicates the volume flow that the vacuum generator evacuates from the environment (free flow).

Free pick flow

Additional suction while workpiece is picked up
**Vacuum Ejectors**

Ejectors work on the Venturi principle. They are divided into single-stage and multi-stage ejectors depending on the number of nozzle pairs.

The compressed air is supplied through the connection (A) to the single-stage ejectors. It flows through the Venturi nozzle (B). The air is accelerated and compressed during this process. After passing through the nozzle, the accelerated air expands once again and a vacuum is created. Air is drawn in this way through the vacuum connection (D). The air that was drawn in and the compressed air escape through the silencer (C).

The Schmalz basic ejectors, inline ejectors and compact ejectors are based on the single-stage Venturi principle.

In addition to the single-stage Venturi principle, there are ejectors in which the vacuum is created by several Venturi nozzles arranged in a row. Compressed air is supplied to the ejector through connection (A). It passes through several Venturi nozzles (B) arranged in a row. A vacuum is created and the air is drawn in through the vacuum connection (D). The suction volumes of the individual nozzles add up to form a total suction rate \( V_2 \). The air that was drawn in and the compressed air escape through the silencer (C).

Compared to single-stage ejectors, multi-stage ejectors create a much higher suction rate in the lower vacuum range using the same amount of compressed air.

The Schmalz multi-stage ejectors are based on the multi-stage Venturi principle.

**Advantages of ejectors**
- Compact shape
- Low weight
- Fast vacuum generation
- No flexible parts, resulting in low maintenance and low wear
- Choose an installation position
- No heat generation

**Typical areas of application**
- Industrial robot applications in all industries, such as feeder applications in the automotive industry
Vacuum Knowledge
The Vacuum System and its Components

We distinguish between three basic types of ejectors:

- Basic- and inline ejectors
- Multi-stage ejectors
- Compact ejectors

**Basic- and inline ejectors**
- Vacuum generators without valve control and system monitoring with high maximum vacuum level (85% vacuum)
- Used mainly to handle air-tight workpieces

**Multi-stage ejectors**
- Vacuum generators with several nozzle chambers arranged in a row with a very high suction rate.
- Used mainly for handling porous workpieces, such as cardboard, chipboards, OSB or MDF sheets

**Compact ejectors**
- Vacuum generators with integrated valve technology and system monitoring, SCpi/SMPi and SXPi/SXMPi series are equipped with IO-Link technology
- Control of pick-up and blow-off feasible without external valves
- Optional with integrated air-saving regulation
- Used in fully automatic handling systems (e.g. sheet metal processing, automotive industry, robot applications)

**Vacuum Pumps**

Vacuum pumps include an eccentrically mounted impeller with lamellae (A) which are pressed against the walls of the housing by centrifugal force and thus provide a seal. As the impeller rotates, the size of each chamber (B) varies. As the chamber becomes larger, the air in it expands and the pressure drops, resulting in a partial vacuum. The air is drawn in through the inlet (C), compressed, and ejected through the outlet (D).

Due to their high compression factor, pumps generate a very high vacuum and, according to the type, have a very high suction capacity.

**Advantages of vacuum pumps**
- High vacuum with high evacuation volume
- Central vacuum generation

**Typical areas of application**
- As central vacuum generation in gantry handling systems
- In manual vacuum handling systems
- In packaging machines
The blades (A) transport, accelerate and compress the air on the momentum principle. The air is dragged by the blades in this case. A vacuum is created at the suction end (B) this way. The compressed air (exhaust air) escapes through the outlet opening (C).

Blowers provide a very high suction rate due to the large air channel volume and specially shaped blades.

**Advantages of vacuum blowers**
- Enormous suction rate
- High leakage compensation
- Evacuation of large volumes in a short time

**Typical areas of application**
- Handling of porous workpieces, such as cardboard, insulation material, chipboards or bags

**Vacuum Blowers**

<table>
<thead>
<tr>
<th>Dry-running pumps</th>
<th>Oil-lubricated pumps</th>
<th>Water-ring pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universal vacuum pumps requiring little maintenance</td>
<td>Vacuum pump with extremely high vacuum level (up to 95% vacuum)</td>
<td>Vacuum pump requiring little maintenance with internal water cooling for handling air-tight workpieces</td>
</tr>
<tr>
<td>Used mainly as central vacuum generator in large gripping systems for handling air-tight workpieces</td>
<td>Used in handling systems with an emphasis on low noise and low maintenance as well as high vacuum, for handling air-tight workpieces</td>
<td>Used especially in areas with high demands on ambient air (e.g. packaging in the food industry)</td>
</tr>
</tbody>
</table>
We distinguish between two basic types of vacuum blowers:

**Vacuum blowers**
- Vacuum blowers are either directly driven or frequency-regulated.
- Used especially for handling porous workpieces (chipboards, bags, etc.).
- Frequency-controlled blowers can be customized by controlling the motor speed and respectively the suction rate.

**Vacuum blowers with reversing**
- Vacuum blower with electro-pneumatic reversing for control of suction, blowing and neutral position.
- Used for handling air-tight workpieces that are picked up and deposited quickly.

**Vacuum Units**

Vacuum units are complete solutions with ejector, monitoring and control. The vacuum unit is used as a purely pneumatic vacuum supply with internal control. The vacuum unit turns off automatically due to the pneumatic control when the set vacuum value is reached while picking up a workpiece.

**Advantages of vacuum units**
- Universal applications
- High suction rate
- Minimum compressed air consumption

**Typical areas of application**
- "Stand-alone solution", for example, for clamping and handling tasks
Valves are used to control vacuum as well as compressed air. They can increase process safety in vacuum gripping systems.

The following functional principles can be distinguished:
- Solenoid valves for vacuum and compressed air
- Check valves and flow resistors; sensing valves
- Manual valves for vacuum and compressed air

**Solenoid Valves**

Solenoid valves are used to control the flow of vacuum and compressed air. The valves themselves are controlled with the aid of electrical signals. Solenoid valves are available in various nominal sizes, permitting selection of a valve which precisely matches the customer-specific requirements. They are available with direct control as well as with pneumatic pilot operation.
Check Valves, Flow Resistors and Sensing Valves

Check valves and flow resistors, as well as sensing valves, increase the process safety and efficiency in a vacuum system.

Check valves interrupt the flow as soon as a certain volume flow has been reached. This will turn off any suction pads in the gripper system that may not be covered completely. The system vacuum will remain intact.

Flow resistors reduce the flow cross-section in the vacuum system and are mainly used in gripper systems for handling porous workpieces. By reducing the flow cross-section, the system vacuum remains intact even if the suction pads are not covered.

Sensing valves open the suction channel with a spring-mounted plunger when a workpiece is present at the suction pad. When the suction pad is occupied (= workpiece present), the line for the vacuum is opened. Sensing valves do not protect the system from partially occupied suction pads.

Non-Return Valves

Non-return valves seal the vacuum system against leakage, for example, in the event of a vacuum failure caused by a power outage. Thus, gripped workpieces are prevented from falling off the gripping system.

Manual Valves

Manual valves are used for manual activation or deactivation of vacuum or compressed air circuits or of individual suction pads in lifting equipment. The valves are available as 2/2-way or 3/2-way valves.
Devices for system monitoring are important for the safe operation of a vacuum system. Schmalz offers measuring as well as control components for this purpose.

We distinguish between the following components for system monitoring and control:
- Vacuum switches
- Pressure switches
- Combined vacuum/pressure switches
- Connection cable and adapter for vacuum switches
- Measuring and control components
- Warning devices

Components for system monitoring are used in all areas of automated handling applications, for example, in feeder systems in the automotive industry, in the plastics industry, as well as in other applications in order to increase process safety.

**Vacuum Switches**

Vacuum switches are available in mechanical and electronic types. In the mechanical versions, the existing vacuum is measured by using a membrane and a microswitch (electromechanical design), or a valve (pneumatic design) is activated. In the electronic version, the vacuum is measured by a piezoresistive sensor and a switching signal (analog or digital) is output.
Vacuum Knowledge

The Vacuum System and its Components

Vacuum switches are used in the measuring range from -1 to 0 bar. There are the following types of vacuum switches:

**Mechanical vacuum switches VS-V-PM and VS-V-EM-ST**
Mechanical vacuum switches are characterized by their sturdy design and their universal operating principle. You can use the electro-mechanical design (EM) to switch DC or AC. The pneumatic design (PM), on the other hand, does not require electrical connections. It works purely with pneumatics. You can set the switching points (with fixed hysteresis) to adapt these switches individually to the process parameters.

**Electronic vacuum switches**
Electronic vacuum switches have a high switching accuracy and repeatability with a very compact design. Vacuum switches with digital display (VS-V-D-… and VS-V-W-D-… version) offer a high level of convenience, because the switching points and hysteresis are fully programmable using a foil keypad. To program the switching point in a process rather quickly and simply, use vacuum switches with teach button (VS-V-AH/AV-T version). You can program the switching points with this version using a key in a matter of seconds. Vacuum switches with analog and digital output (VS-V and VS-V-A-… versions) and vacuum switches in miniature form (VS-V-SA/SD) round off the program.

**Pressure Switches**

Electronic pressure switches are used in the measuring range from 0 to 10 bar. Pressure switches with digital display (VS-P10-D/VS-P10-W-D) are easy to operate. The switching points and hysteresis are fully programmable using a foil keypad. They are used when there are high requirements for switching accuracy and repeatability as well as implementation of short switching times. Pressure switches with teach button (VS-P10AH/AV-T-PNP (-S)) are particularly suited to program switching points quickly and easily. Pressure switches with analog and digital output (VS-P1 version) can also be used as pressure sensors due to their two outputs.

**Combined Vacuum/Pressure Switches**
Combined vacuum/pressure switches (VS-P) are used in the measuring range from -1 to 10 bar. The switching accuracy is reduced by the large measuring range. They are available with two switching outputs (digital and analog) and can also be used as a vacuum sensor or a pressure sensor for this reason.
Connections and Adapters for Vacuum Switches

Matching connection cables and adapters are available for the different types of switches. The cables and connectors are adapted to meet the customer-specific requirements and local standards.

Measuring and Control Components

Vacuum regulators can be adjusted mechanically. They guarantee a precise setting with high repeatability. Vacuum regulators compensate for pressure differences of vacuum generators caused by their design.

Pressure-reduction valves are used to set a specific output pressure when the pressure on the input end (input pressure) is higher than necessary.

Manometers measure and display the vacuum in analog form. They can be used for all vacuum applications because of their standardized dimensions and connections.

Warning Devices

Warning devices are used for monitoring and warning in the event of a vacuum failure or a power failure. They sound an acoustic warning signal with 100 dB. The switching point can be set from -1 to 0 bar and provides flexible use at different vacuum levels.
Vacuum systems are protected by the use of filters. The filters protect the vacuum generator from contamination. Suction pads and vacuum generator are connected with each other by hoses and connectors.

Schmalz offers the following products:
- Vacuum filters
- Vacuum distributors
- Hoses and connectors

Vacuum Filters

Filters are used to protect the vacuum generator or the valve in dusty environments. The filters are installed in the system between the suction pad and the vacuum generator or the valve.

Vacuum filters are often installed as central filter in the system. The vacuum filters have a degree of separation of almost 100%.

Vacuum cup filters are installed as decentralized filters directly in the vacuum line at the suction pad. Vacuum cup filters are used with light to medium contamination.

Inline filters are installed as decentralized filters directly in the vacuum line at the suction pad. Inline filters are used with small flows and light contamination.
Vacuum Knowledge

The Vacuum System and its Components

**Vacuum Distributor**

The vacuum distributors can be used with centralized or decentralized vacuum generation. In systems with decentralized vacuum generation, compressed air is distributed to the individual ejectors by the distributor. In systems with centralized vacuum generation, the vacuum is distributed from the vacuum generator to the individual suction pads by the distributor.

**Hoses and Connectors**

Schmalz offers all hoses and connections that are needed to set up a functioning vacuum system. The products range from vacuum hoses to plug-in screw unions and sealing rings, all the way to hose clamps.
Vacuum Knowledge

Basic Vacuum Knowledge and Vacuum Terminology

**Definition of Vacuum**

Vacuum is the term for air pressures which lie below normal atmospheric pressure. The ambient pressure is 1,013 mbar at sea level and decreases with elevation.

The form of the vacuum depends on the application in vacuum technology. A relatively small vacuum, the low vacuum, is sufficient for vacuum handling.

The pressure of the low vacuum ranges from 1 mbar to 1,013 mbar (ambient pressure at sea level).

**Specification as relative value**

In vacuum technology, the vacuum is specified as a relative value which means the vacuum is specified in relation to the ambient pressure. Such vacuum values always have a negative sign, because the ambient pressure is used as the reference point, which is defined as 0 mbar.

<table>
<thead>
<tr>
<th>Underpressure / Vacuum</th>
<th>Overpressure +1,000 mbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient pressure</td>
<td></td>
</tr>
</tbody>
</table>

**Specification as absolute value**

In science, a vacuum is specified as an absolute value. The reference point is absolute zero, which means space void of air (e.g. outer space). This means the vacuum value is always positive.

<table>
<thead>
<tr>
<th>Absolute value</th>
<th>+500</th>
<th>+1,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following table shows the comparison values between absolute and relative pressure.

<table>
<thead>
<tr>
<th>Vacuum/pressure conversion table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute pressure [mbar]</td>
</tr>
<tr>
<td>Relative</td>
</tr>
<tr>
<td>900</td>
</tr>
<tr>
<td>800</td>
</tr>
<tr>
<td>700</td>
</tr>
<tr>
<td>600</td>
</tr>
<tr>
<td>500</td>
</tr>
<tr>
<td>400</td>
</tr>
<tr>
<td>300</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>100</td>
</tr>
</tbody>
</table>

At the end of this chapter you will find additional conversion and unit tables.
Basic Vacuum Knowledge and Vacuum Terminology

Measurement Units for Vacuum Data

The units pascal [Pa], kilopascal [kPa], bar [bar] and millibar [mbar] are most widely used in vacuum technology as units for pressure. The units are converted as follows:

0.001 bar = 0.1 kPa = 1 mbar = 100 Pa

In this catalog, all absolute pressure values are given in bar or mbar, all relative values in %. The % value is typical for a relative indication of the efficiency of a vacuum generator. Other units are used internationally. Some of them are included in the following table.

<table>
<thead>
<tr>
<th>Vacuum/pressure conversion table</th>
<th>bar</th>
<th>N/cm²</th>
<th>kPa</th>
<th>atm, kp/cm²</th>
<th>mm H₂O</th>
<th>Torr, mm Hg</th>
<th>in Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>bar</td>
<td>1.00000</td>
<td>10.0000</td>
<td>100.000</td>
<td>1.0197</td>
<td>10,197.0</td>
<td>750.0600</td>
<td>29.540</td>
</tr>
<tr>
<td>N/cm²</td>
<td>0.10000</td>
<td>1.0000</td>
<td>10.000</td>
<td>0.1019</td>
<td>1,019.70</td>
<td>75.0060</td>
<td>2.9540</td>
</tr>
<tr>
<td>kPa</td>
<td>0.01000</td>
<td>0.1000</td>
<td>1.000</td>
<td>0.0102</td>
<td>101.97</td>
<td>7.5006</td>
<td>0.2954</td>
</tr>
<tr>
<td>atm, kp/cm²</td>
<td>0.98070</td>
<td>9.8070</td>
<td>98.070</td>
<td>1.0000</td>
<td>10,332.00</td>
<td>735.5600</td>
<td>28.9700</td>
</tr>
<tr>
<td>mm H₂O</td>
<td>0.00010</td>
<td>0.0010</td>
<td>0.010</td>
<td>0.0000</td>
<td>1.00</td>
<td>0.0740</td>
<td>0.0030</td>
</tr>
<tr>
<td>Torr, mm Hg</td>
<td>0.00133</td>
<td>0.0133</td>
<td>0.133</td>
<td>0.00136</td>
<td>13.60</td>
<td>1.0000</td>
<td>0.0394</td>
</tr>
<tr>
<td>in Hg</td>
<td>0.03380</td>
<td>0.3385</td>
<td>3.885</td>
<td>0.03446</td>
<td>345.40</td>
<td>25.2500</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

At the end of this chapter you will find additional conversion and unit tables.

Energy Required for Vacuum Generation

The energy required for vacuum generation increases disproportionately to the attained vacuum. Increasing the vacuum from -600 mbar to -900 mbar, for example, increases the holding force by a factor of 1.5, but the evacuation time and the energy needed to achieve this vacuum value increases by a factor of 3.

This means that only the vacuum required should be generated in the working area to keep the energy expenditure and the operating costs at a minimum.

Common working areas

- for air-tight surface (e.g. metal, plastics, etc.): -600 to -800 mbar vacuum
- for porous materials (e.g. cardboard boxes, particle boards, MDF sheets, etc.): -200 to -400 mbar vacuum; in this range the necessary holding force is generated by increasing the suction rate and the suction area.

Important:

In this catalog, the holding forces of the suction pads are always specified at an efficient vacuum level of -600 mbar.
The air pressure (ambient pressure) depends on the elevation of the location as well as the temperature at that site. As shown in the diagram, the air pressure at sea level is 1,013 mbar. At an elevation of 600 m (location of the J. Schmalz GmbH in Glatten, Germany) air pressure is reduced to 938 mbar. At a height of 2,000 m, the air pressure is only 763 mbar.

This pressure loss also has an effect on working with a vacuum. The pressure drop with increasing height also reduces the maximum pressure difference that can be attained and therefore the maximum holding force. Per 100 m increase in elevation, the air pressure drops by about 12.5 mbar.

A vacuum generator that generates an 80% vacuum, achieves a vacuum value of -810 mbar at sea level (ambient pressure = 1,013 mbar); at 2,000 m (ambient pressure = 763 mbar) a vacuum generator only achieves -610 mbar. The possible holding force of a vacuum suction pad drops proportionally to the vacuum value that can be attained. This means the application at sea level presents the best case scenario.

**Important:**

All data in this catalog refer to an ambient pressure of 1,013 mbar and an ambient temperature of 20 °C.
Approach to System Design

The implementation from theory to practice is shown with a system design based on an example. The Schmalz Calculator offers helpful support during the system design and is available for free download at www.schmalz.com.

The following calculations are based on this application:

### Workpiece

| Material: | Steel sheets, stacked on a pallet |
| Surface: | Smooth, level, dry |
| Dimensions: | Length: max. 2,500 mm |
| | Width: max. 1,250 mm |
| | Thickness: max. 2.5 mm |
| Weight: | approx. 60 kg |

### Handling system

| Used system: | Gantry handling system |
| Existing compressed air: | 8 bar |
| Control voltage: | DC 24 V |
| Working sequence: | Horizontal Pick & Place |

A steel sheet is picked up from a pallet, lifted, transported horizontally and deposited in a machining center.

| Max. acceleration: | X, Y axis: 5 m/s² |
| | Z axis: 5 m/s² |
| Cycle time: | 30 s |
| Scheduled time: for pick-up: | < 1s |
| for releasing: | < 1s |
It is important to determine the weight \( m \) of the workpiece to continue with additional calculations. It is calculated based on the following formula:

\[
m = L \times B \times H \times \rho
\]

- \( m \) = Weight [kg]
- \( L \) = Length [m]
- \( B \) = Width [m]
- \( H \) = Height [m]
- \( \rho \) = Density [kg/m³]

Our example:

\[
m = 2.5 \text{ m} \times 1.25 \text{ m} \times 0.0025 \text{ m} \times 7,850 \text{ kg/m}^3
\]

\[
m = 61.33 \text{ kg}
\]

### Theoretical Holding Force of a Suction Pad

The suction pads not only have to be able to carry the weight of the workpiece but must also be capable of handling the acceleration forces. These may never be neglected in a fully automated process.

To calculate the theoretical holding force, we show and describe the three most important and most frequently occurring load cases (handling sequences).

Important:

For the following, simplified representations of the load cases the calculation must be based on the worst load case with the highest, theoretical holding force. This is the only way to ensure that the suction pad grips the workpiece safely during the entire handling process.

The safety factor is a minimum value of 1.5 for smooth and dense workpieces. A safety factor of 2.0 or greater must be used for critical, diverse or varied, porous or rough workpieces. If factors such as acceleration or friction coefficient are not known or cannot be determined precisely, a value of 2.0 or higher should also be used.

**Load case I – Suction pad horizontal, direction of force vertical**

The workpiece (in this case the steel sheet with the dimensions 2.5 x 1.25 m) is lifted from a pallet. The workpiece is lifted with an acceleration of 5 m/s² (no transverse movement).

\[
F_{TH} = m \times (g + a) \times S
\]

- \( F_{TH} \) = theoretical holding force [N]
- \( m \) = Weight [kg]
- \( g \) = Gravity [9.81 m/s²]
- \( a \) = Acceleration [m/s²] of the system
- \( S \) = Safety factor (minimum value 1.5 times safety; for critical, diverse or varied or porous materials or rough surfaces 2.0 or even higher)

Our example:

\[
F_{TH} = 61.33 \text{ kg} \times (9.81 \text{ m/s}^2 + 5 \text{ m/s}^2) \times 1.5
\]

\[
F_{TH} = 1,363 \text{ N}
\]

The suction pads land on a workpiece vertically that is to be lifted up.
**Load case II – Suction pad horizontal, direction of force horizontal**

The workpiece (in this case the steel sheet with the dimensions 2.5 x 1.25 m) is lifted up vertically and transported horizontally. The acceleration is 5 m/s².

\[
F_{TH} = m \times (g + a/\mu) \times S
\]

- \(F_{TH}\) = theoretical holding force \([N]\)
- \(F_a\) = Acceleration force \(= m \cdot a\)
- \(m\) = Weight \([kg]\)
- \(g\) = Gravity \([9.81 \text{ m/s}^2]\)
- \(a\) = Acceleration \([\text{m/s}^2]\) of the system (keep in mind Emergency Stop situations!)
- \(\mu\) = Friction coefficient = 0.1 for oily surfaces
  = 0.2 to 0.3 for wet surfaces
  = 0.5 for wood, metal, glass, stone etc.
  = 0.6 for rough surfaces

Caution! The specified values for friction coefficient are averaged and must be checked for the individual workpiece!

\(S\) = Safety (minimum value 1.5 times safety, for critical, diverse or varied or porous materials or rough surfaces 2.0 or even higher)

Our example:

\[
F_{TH} = 61.33 \text{ kg} \times (9.81 \text{ m/s}^2 + 5 \text{ m/s}^2 /0.5) \times 1.5
\]

\[
F_{TH} = 1,822 \text{ N}
\]

**Load case III – Suction pad vertical, direction of force vertical**

Description of load case: The workpiece (in this case the steel sheet with the dimensions 2.5 x 1.25 m) is picked up from a pallet and moved with a rotary motion at an acceleration of 5 m/s².

\[
F_{TH} = (m/\mu) \times (g + a) \times S
\]

- \(F_{TH}\) = theoretical holding force \([N]\)
- \(m\) = Weight \([kg]\)
- \(g\) = Gravity \([9.81 \text{ m/s}^2]\)
- \(a\) = Acceleration \([\text{m/s}^2]\) of the plant (keep in mind Emergency Stop situations!)
- \(\mu\) = Friction coefficient = 0.1 for oily surfaces
  = 0.2 to 0.3 for wet surfaces
  = 0.5 for wood, metal, glass, stone etc.
  = 0.6 for rough surfaces

\(S\) = Safety (minimum value 2.0 times safety, for critical, diverse or varied or porous materials or rough surfaces even higher)

Our example:

\[
F_{TH} = (61.33 \text{ kg} /0.5) \times (9.81 \text{ m/s}^2 + 5 \text{ m/s}^2) \times 2
\]

\[
F_{TH} = 3,633 \text{ N}
\]

**Comparison:**

For our scenario, the workpiece is lifted off a pallet, moved to the side and placed on a machining center. The rotary motion from load case III is not needed in this application, therefore one only needs to consider the result from load case II.

The result in this case is a maximum theoretical holding force \((F_{TH})\) of 1,822 N. This theoretical holding force acts on the suction pad during horizontal transport of the workpiece. The following calculations are based on this value to safely solve the task.
Suction Pad Selection

The calculated theoretical holding force corresponds to the force that the suction pads must create to safely handle the workpiece. To select the suction pads, one must also take the ambient conditions and the application into consideration. The selection of the suction pads usually takes place based on the following criteria:

Application: The operating conditions on site are crucial for the selection of the suction pad, such as multi-shift operation, service life, chemically aggressive environment, temperature.

Material: Suction pads made of different materials are available to meet the requirements, such as those particularly suited for smooth or rough surfaces, oily or very fragile workpieces, anti-static suction pads for electronic components, suction pads leaving few marks for fragile plastic parts, etc. The selection of the suitable suction pad material for handling of workpieces is described in a comprehensive table in the chapter “Vacuum Suction Pads”.

Surface: Depending on the condition of the surface, we recommend suction pads in specific shapes. You can select from flat or bellows suction pads with different sealing lips and sealing edges in different shapes and geometries. An overview of the different suction pads and the specific advantages of the individual suction pad types is included in the chapter “Vacuum Suction Pads”.

For this example we choose:
Flat suction pad of the type PFYN made of Perbunan NBR
This suction pad is a cost-efficient solution for handling smooth, level workpieces. Data for this type is available on the respective pages in the chapter “Vacuum Suction Pads”.

To solve the example, the calculated theoretical holding force can be applied by one suction pad or distributed among several suction pads. The number of suction pads used depends on the respective application.

For the steel sheet (2,500 x 1,250 mm) from the present case, one would usually use six or eight suction pads. The most important criterion for the number of suction pads in this example, is the flexing of the steel sheet during transport. Depending on the number of used suction pads, the required diameter of these suction pads changes.

Calculation of suction force $F_s$ [N] for individual suction pad

$F_s = \frac{F_{TH}}{n}$

- $F_s = $ Suction force
- $F_{TH} = $ Theoretical holding force
- $n = $ Number of suction pads

Our example: $F_s = \frac{1,822 N}{6}$

$F_s = 304 N$

According to the technical data for the suction pad PFYN, one needs 6 x PFYN 95 NBR with a diameter of 95 mm and a suction force of 350 N each.

$F_s = \frac{1,822 N}{8}$

$F_s = 228 N$

According to the technical data for the suction pad PFYN, one needs 8 x PFYN 80 NBR with a diameter of 80 mm and a suction force of 260 N each.

For this example we choose:
Six suction pads of type PFYN 95 NBR
With a sheet thickness of 2.5 mm, six suction pads ensure a secure sheet pick.

Important:
- The suction force of the individual suction pads is listed in the table “Technical data” for the respective suction pad in the chapter “Vacuum Suction Pads”.
- The suction force of the suction pad must exceed the calculated theoretical holding force.
Vacuum Knowledge

System Design – Calculation Example

**Mounting Element Selection**

The mounting of the suction pads is usually selected according to customer requirements. But there may be compelling reasons for a particular type of mounting:

**Uneven or inclined surfaces**

The suction pad must be able to adapt to the incline:

> Joint mounting

**Different heights/thicknesses**

To compensate for height difference, one needs a spring-supported mounting:

> Spring plunger

In this case, the steel sheets are stacked on a pallet. If the sheets are larger than the pallet, one must assume that the ends of the sheets are hanging down. This means the suction pads must be able to compensate for height differences and inclines.

*For this example we choose:*

**Joint Flexolink FLK 1/4" – 1/4" female thread**

Optimum flexibility of suction pads for inclined workpiece surfaces.

**Spring plunger FSTE 1/4" – 75 stroke**

Greatest stroke because of sheets hanging down from pallet, 1/4" thread for connection to selected joint mounting Flexolink FLK.

**Note:**

Make sure when you select the mounting elements that these can be screwed onto the suction pads, which means the threads have to match. This also ensures maintaining the carrying capacities. The different mounting options and technical data are listed in the chapter "Mounting Elements".

**Vacuum Hose Selection**

The vacuum hoses are selected to match the size of the volume flows as well as the size of the suction pads. The table "Technical data" includes a recommendation for a hose cross section on the respective page of the suction pad and the ejector. The different hoses are listed in the chapter "Filters and Connectors".

*For this example we choose:*

**Vacuum hose VSL 8/6** with an internal diameter of 6 mm

See table "Technical data" for the suction pad of type PFYN 95 NBR used in this example.
**Distributor Selection**

The distributor has to match the used hose diameter and the number of suction pads.

**Example:**
The hose VSL 8/6 has an outside diameter of 8 mm and an internal diameter of 6 mm. Six suction pads are used.

**For this example we choose:**
Plug-in screw unions STV-GE G1/4-AG 8 for the hose VSL 8/6 with outside diameter 8 mm and internal diameter 6 mm as well as 1/4” thread matching the female thread of the distributor.

Plug-in screw union STV-GE G3/8-AG 8 fits the spring plunger.

Distributor VTR G3/8-IG 9xG1/4 with one input (3/8” thread) and nine outputs (1/4” thread).

Three sealing screws VRS-SB G1/4-AG to close the three open outputs.

**Vacuum Generator Selection**

The selection of the matching vacuum generator (ejector, pump or blower) is determined by several factors:

- Type of workpieces: porous, air-tight
- Energy supply options: a lower case electricity, compressed air
- Restrictions for size and weight
- Maintaining cycle times

<table>
<thead>
<tr>
<th>Short cycle times:</th>
<th>Ejector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long transport distances:</td>
<td>Pump or blower</td>
</tr>
</tbody>
</table>

**Selection table for generator type by application**

<table>
<thead>
<tr>
<th>materials</th>
<th>cycle times</th>
<th>power supply</th>
<th>transport path</th>
</tr>
</thead>
<tbody>
<tr>
<td>air-tight</td>
<td>porous</td>
<td>very short, &lt;0.5sec</td>
<td>compr. air</td>
</tr>
<tr>
<td>Ejector</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Pump</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Blower</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

*Only with automatic air-saver (LSP) and air-tight materials

**For this example we choose:**
Ejector to generate vacuum.

Because the workpiece in this case is air-tight, you can create a simple and lightweight structure while implementing short pick-up and release times.
Suction rate of vacuum generator

The diameter of the suction pad determines the suction rate that a vacuum generator has to apply to evacuate the suction pad. The suitable suction rate is described in the table “Technical data” of the respective vacuum generator.

Based on experience and measurements with system designs, we recommend a selection based on the following table:

<table>
<thead>
<tr>
<th>Suction-pad Ø</th>
<th>Suction capacity $V_S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 60 mm</td>
<td>0.5 m³/h, 8.3 l/min</td>
</tr>
<tr>
<td>Up to 120 mm</td>
<td>1.0 m³/h, 16.6 l/min</td>
</tr>
<tr>
<td>Up to 215 mm</td>
<td>2.0 m³/h, 33.3 l/min</td>
</tr>
<tr>
<td>Up to 450 mm</td>
<td>4.0 m³/h, 66.6 l/min</td>
</tr>
</tbody>
</table>

Note:
The specified values apply regardless of the type of vacuum generation. The recommended suction ratio applies per suction pad and only for smooth, air-tight surfaces. For porous, permeable workpieces we recommend conducting a corresponding suction trial with the original workpiece.

Calculation of the suction rate $V$ [m³/h, l/min], that the vacuum generator has to apply

$V = n \times V_S$

$n = \text{Number of suction pads}$

$V_S = \text{Required suction rate for an individual suction pad}$

[m³/h, l/min]

Example:

$V = 6 \times 16.6$ l/min

$V = 99.6$ l/min

For this example we choose:

Compact ejector SCPi 20 with a suction rate of 140 l/min.

The compact ejector offers valves for control of the “suction” and “blow off” functions as well as system monitoring for ensuring process safety during handling. The compact ejector SCPi is also equipped with IO-Link Technology. It makes the various diagnostic functions visible and usable on the control level. This increases system availability and makes automation processes even more efficient.

Valve Technology Selection

In this case we are using a compact ejector with integrated valve technology. In other cases we need solenoid valves to switch the function “Vacuum on/off”. They are usually used when pumps or blowers are used as vacuum generators.

The selection of the valves is based on the following criteria:

- Suction rate of vacuum generator
- Control voltage
- Operating principle of the valve (NO/NC)

The nominal flow of the solenoid valve may not be less than the suction ratio of the vacuum generator.
Vacuum Knowledge

System Design – Calculation Example

Calculation of the nominal size of the valve:

\[ V_V = V_{VE} \]

- \( V_V \): Nominal flow of valve \([\text{m}^3/\text{h}, \text{l}/\text{min}]\)
- \( V_{VE} \): Existing suction rate of vacuum generator \([\text{m}^3/\text{h}, \text{l}/\text{min}]\)

The nominal flow is listed in the “Technical data” of the respective valve and the suction rate is listed in the “Technical data” of the respective vacuum generator.

Example: \( V_V = 116 \text{ l/min} = 7 \text{ m}^3/\text{h} \)

For this example we choose:

The used compact ejector of type SCPi 20 is equipped with solenoid valves which eliminates the need for separate valves. A solenoid valve of type EMV-10 with a nominal flow of 20 \( \text{m}^3/\text{h} \) would also be sufficient for the function Suction ON/OFF.

Vacuum Switch Selection

Vacuum switches and manometers are usually selected based on the existing requirements regarding functionality and switching frequency.

The following functions are available:
- Adjustable switching point
- Hysteresis fixed or adjustable
- Signal output digital and/or analog
- Function LED
- Display with input keyboard
- Vacuum connection M5-IG, M8-AG, flange or tube insert
- Supply and signal connection with cable or M8 plug

The available versions with their respective technical data are explained in the chapter “Switches and System Monitoring”.

For this example we choose:

The used compact ejector of the type SCPI 20 is equipped with an integrated system monitoring (digital output signals). There is no need for an additional vacuum switch.

You can use vacuum switches or manometers for vacuum generators without system monitoring.
Vacuum Knowledge
System Design – Calculation Example

**Calculation of Evacuation Times**

The entire volume that has to be evacuated is required to calculate the efficiency of the vacuum system.

\[ V_G = V_1 + V_2 + V_3 + V_4 + V_5 + \ldots \]

- \( V_G \) = Volume to be evacuated [m³]
- \( V_1 \) = Volume of suction pads [m³]
- \( V_2 \) = Volume of mounting elements [m³]
- \( V_3 \) = Volume of vacuum hoses [m³]
- \( V_4 \) = Volume of distributor [m³]
- \( V_5 \) = Volume of prefilter (if necessary) [m³]
- \( V_6 \) = Volume of solenoid valve (if necessary) [m³]

**Example:**

\[ V_G = 6 \times 32 \text{ cm}^3 + 6 \times 9.5 \text{ cm}^3 + 6 \times 43 \text{ cm}^3 + 1 \times 38.5 \text{ cm}^3 \]
\[ V_G = 546 \text{ cm}^3 = 0.000546 \text{ m}^3 \]

**Calculation of evacuation time \( t \) [h]**

\[ t = \left( \frac{V_G \times \ln (P_a/P_e) \times 1.3)}{V} \right) \]

- \( V_G \) = Volume to be evacuated [m³]
- \( \ln \) = Natural logarithm
- \( P_a \) = Absolute start pressure [1,013 mbar]
- \( P_e \) = Absolute final pressure [mbar]
- \( V \) = Suction rate of vacuum generator [m³/h]

**Example:**

\[ t = \left( \frac{(0.000546 \text{ m}^3 \times \ln (1,013 \text{ mbar} / 400 \text{ mbar}) \times 1.3)}{6.95 \text{ m}^3} \right) \]
\[ t = 0.0000949 \text{ h} = 0.34 \text{ sec} \]

The evacuation time of the entire system is 0.34 seconds. The system is cost-optimized and efficient, shorter cycle times are possible.

**Test with Original Parts**

A complete and energy-efficient vacuum system has been assembled from the Schmalz vacuum components. You should still conduct tests with original sample workpieces. The theoretical system design gives you a feeling for the size of the system. Schmalz has its own test center in which we conduct practical tests.

We will be glad to assist you with our expertise and many years of experience, from planning all the way to commissioning of your vacuum system. A comprehensive range of trainings and seminars rounds off our program.
Symbols in Vacuum Technology

Circuit diagrams and function charts are used in vacuum technology to visualize vacuum systems. These diagrams/charts include symbols for certain components or modules. The following overview represents the most important and common symbols of vacuum components from Schmalz.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Component</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Symbol" /></td>
<td>Valve (general)</td>
</tr>
<tr>
<td><img src="image2" alt="Symbol" /></td>
<td>Ball cock, two-way</td>
</tr>
<tr>
<td><img src="image3" alt="Symbol" /></td>
<td>Ball cock, three-way</td>
</tr>
<tr>
<td><img src="image4" alt="Symbol" /></td>
<td>Manual slide valve, three-way</td>
</tr>
<tr>
<td><img src="image5" alt="Symbol" /></td>
<td>Solenoid valve, 3/2-way, pneumatic pilot operation</td>
</tr>
<tr>
<td><img src="image6" alt="Symbol" /></td>
<td>Filter</td>
</tr>
<tr>
<td><img src="image7" alt="Symbol" /></td>
<td>Manometer</td>
</tr>
<tr>
<td><img src="image8" alt="Symbol" /></td>
<td>Vacuum-pressure switch</td>
</tr>
<tr>
<td><img src="image9" alt="Symbol" /></td>
<td>Check valve</td>
</tr>
<tr>
<td><img src="image10" alt="Symbol" /></td>
<td>Pressure-limiter valve</td>
</tr>
<tr>
<td><img src="image11" alt="Symbol" /></td>
<td>Non-return valve</td>
</tr>
<tr>
<td><img src="image12" alt="Symbol" /></td>
<td>Sensing valve</td>
</tr>
<tr>
<td><img src="image13" alt="Symbol" /></td>
<td>Flow resistor</td>
</tr>
<tr>
<td><img src="image14" alt="Symbol" /></td>
<td>Special suction pad</td>
</tr>
<tr>
<td><img src="image15" alt="Symbol" /></td>
<td>Flat suction pad with single lip</td>
</tr>
<tr>
<td><img src="image16" alt="Symbol" /></td>
<td>Flat suction pad with double lip</td>
</tr>
<tr>
<td><img src="image17" alt="Symbol" /></td>
<td>Flat suction pad with sealing profile</td>
</tr>
<tr>
<td><img src="image18" alt="Symbol" /></td>
<td>Bellows suction pad</td>
</tr>
<tr>
<td><img src="image19" alt="Symbol" /></td>
<td>Spring plunger</td>
</tr>
<tr>
<td><img src="image20" alt="Symbol" /></td>
<td>Flexlink, ball joint</td>
</tr>
<tr>
<td><img src="image21" alt="Symbol" /></td>
<td>Sealing cord</td>
</tr>
<tr>
<td><img src="image22" alt="Symbol" /></td>
<td>Adapter nipple</td>
</tr>
<tr>
<td><img src="image23" alt="Symbol" /></td>
<td>Ejector, single-stage</td>
</tr>
<tr>
<td><img src="image24" alt="Symbol" /></td>
<td>Ejector, multi-stage</td>
</tr>
<tr>
<td><img src="image25" alt="Symbol" /></td>
<td>Silencer</td>
</tr>
<tr>
<td><img src="image26" alt="Symbol" /></td>
<td>Vacuum blower</td>
</tr>
<tr>
<td><img src="image27" alt="Symbol" /></td>
<td>Vacuum pump</td>
</tr>
<tr>
<td><img src="image28" alt="Symbol" /></td>
<td>Vacuum regulator</td>
</tr>
<tr>
<td><img src="image29" alt="Symbol" /></td>
<td>Hose</td>
</tr>
<tr>
<td><img src="image30" alt="Symbol" /></td>
<td>Reservoir</td>
</tr>
</tbody>
</table>

Circuit diagrams for all relevant vacuum components are available in the operating instructions online at www.schmalz.com/operating-instructions. Examples of vacuum circuit diagrams:

Example: Vacuum circuit with basic ejector

Example: Vacuum circuit with controlled compact ejector

Example: Vacuum circuit with vacuum center and vacuum-controlled motor circuit
# Units and Symbols

## Dimensions and Volume

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit in Schmalz catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>l</td>
<td>mm, m</td>
</tr>
<tr>
<td>Width</td>
<td>b</td>
<td>mm, m</td>
</tr>
<tr>
<td>Height</td>
<td>h</td>
<td>mm, m</td>
</tr>
<tr>
<td>Diameter</td>
<td>d</td>
<td>mm, m</td>
</tr>
<tr>
<td>Volume</td>
<td>V</td>
<td>m³, l</td>
</tr>
</tbody>
</table>

## Force

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit in Schmalz catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>F</td>
<td>N, kg x m/s²</td>
</tr>
<tr>
<td>Theoretical holding force</td>
<td>Fₜₙ</td>
<td>N</td>
</tr>
<tr>
<td>Acceleration</td>
<td>Fₐ</td>
<td>N</td>
</tr>
<tr>
<td>Tear-off force</td>
<td>Fₜ</td>
<td>N</td>
</tr>
<tr>
<td>Weight</td>
<td>G</td>
<td>N</td>
</tr>
<tr>
<td>Friction coefficient</td>
<td>μ</td>
<td>-</td>
</tr>
</tbody>
</table>

## Temperature

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit in Schmalz catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>t</td>
<td>°C</td>
</tr>
</tbody>
</table>

## Vacuum Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit in Schmalz catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure, absolute</td>
<td>p</td>
<td>mbar, bar</td>
</tr>
<tr>
<td>Pressure difference</td>
<td>∆p</td>
<td>mbar, bar</td>
</tr>
<tr>
<td>Initial pressure</td>
<td>Pₐ</td>
<td>mbar, bar</td>
</tr>
<tr>
<td>Final pressure</td>
<td>Pₖ</td>
<td>mbar, bar</td>
</tr>
<tr>
<td>Negative pressure / vacuum</td>
<td>Pᵥ</td>
<td>mbar, bar</td>
</tr>
<tr>
<td>Suction rate</td>
<td>Vₛ</td>
<td>l/min, m³/h</td>
</tr>
<tr>
<td>Required suction rate</td>
<td>Vₘ</td>
<td>l/min, m³/h</td>
</tr>
<tr>
<td>Nominal flow of solenoid valve</td>
<td>Vᵥ</td>
<td>l/min, m³/h</td>
</tr>
<tr>
<td>Present suction rate of vacuum generator</td>
<td>Vᵥₑ</td>
<td>l/min, m³/h</td>
</tr>
<tr>
<td>Total volume to be evacuated</td>
<td>Vₙₑ</td>
<td>m³, l</td>
</tr>
</tbody>
</table>

## Weight

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit in Schmalz catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>m</td>
<td>g, kg</td>
</tr>
<tr>
<td>Density</td>
<td>p</td>
<td>kg/m³</td>
</tr>
</tbody>
</table>

## Time

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit in Schmalz catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration, evacuation time</td>
<td>t</td>
<td>ms, s, min, h</td>
</tr>
<tr>
<td>Speed</td>
<td>v</td>
<td>m/s</td>
</tr>
<tr>
<td>Acceleration</td>
<td>a, g</td>
<td>m/s², g</td>
</tr>
</tbody>
</table>

## Electrical and Magnetic Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit in Schmalz catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>U</td>
<td>V</td>
</tr>
<tr>
<td>Strength of current</td>
<td>I</td>
<td>A</td>
</tr>
</tbody>
</table>

## Other Information

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit in Schmalz catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety factor</td>
<td>S</td>
<td>-</td>
</tr>
<tr>
<td>Quantity of suction pads</td>
<td>n</td>
<td>-</td>
</tr>
<tr>
<td>Natural logarithm</td>
<td>ln</td>
<td>-</td>
</tr>
<tr>
<td>Noise level / sound pressure level</td>
<td>lₚ</td>
<td>dB</td>
</tr>
</tbody>
</table>
## Conversion tables

### Length

<table>
<thead>
<tr>
<th></th>
<th>m</th>
<th>ft</th>
<th>in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m</td>
<td>1.000</td>
<td>3.281</td>
<td>39.370</td>
</tr>
<tr>
<td>1 ft (foot)</td>
<td>0.305</td>
<td>1.000</td>
<td>12.000</td>
</tr>
<tr>
<td>1 in (inch)</td>
<td>0.025</td>
<td>0.083</td>
<td>1.000</td>
</tr>
</tbody>
</table>

### Mass

<table>
<thead>
<tr>
<th></th>
<th>kg</th>
<th>lb</th>
<th>oz</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kg</td>
<td>1</td>
<td>2.20</td>
<td>35.27</td>
</tr>
<tr>
<td>1 lb (pound)</td>
<td>0.45</td>
<td>1</td>
<td>16</td>
</tr>
<tr>
<td>1 oz (ounce)</td>
<td>0.03</td>
<td>0.06</td>
<td>1</td>
</tr>
</tbody>
</table>

### Temperature

<table>
<thead>
<tr>
<th></th>
<th>°C</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Kelvin</td>
<td>-272.15</td>
<td>-457.87</td>
</tr>
<tr>
<td>1 °Celsius</td>
<td>274.15</td>
<td>1</td>
</tr>
<tr>
<td>1 °Fahrenheit</td>
<td>255.93</td>
<td>1</td>
</tr>
</tbody>
</table>

### Suction rate

<table>
<thead>
<tr>
<th></th>
<th>m³/s</th>
<th>l/s</th>
<th>m³/h</th>
<th>l/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m³/s</td>
<td>1</td>
<td>3,600</td>
<td>1</td>
<td>60,000</td>
</tr>
<tr>
<td>1 l/s</td>
<td>1,000</td>
<td>1</td>
<td>0.278</td>
<td>16.67</td>
</tr>
<tr>
<td>1 m³/h</td>
<td>2.78 x 10⁻⁴</td>
<td>0.278</td>
<td>1.67 x 10⁻¹</td>
<td>0.06</td>
</tr>
<tr>
<td>1 l/min</td>
<td>60,000</td>
<td>60</td>
<td>16.67</td>
<td>1</td>
</tr>
</tbody>
</table>

### Volume

<table>
<thead>
<tr>
<th></th>
<th>m³</th>
<th>cm³</th>
<th>l</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m³</td>
<td>1</td>
<td>1 x 10⁶</td>
<td>1,000</td>
</tr>
<tr>
<td>1 cm³</td>
<td>1 x 10⁻⁶</td>
<td>1</td>
<td>1 x 10⁻³</td>
</tr>
</tbody>
</table>

### Vacuum ranges

<table>
<thead>
<tr>
<th></th>
<th>Absolute pressure in mbar</th>
<th>Mean free path of atoms*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low vacuum</td>
<td>1,000 – 1</td>
<td>68 nm – 0.1 mm</td>
</tr>
<tr>
<td>Medium vacuum</td>
<td>1 – 10⁻³</td>
<td>0.1 mm – 100 mm</td>
</tr>
<tr>
<td>High vacuum</td>
<td>10⁻³ – 10⁻⁷</td>
<td>100 mm – 1 km</td>
</tr>
<tr>
<td>Ultra high vacuum</td>
<td>&lt; 10⁻⁷</td>
<td>&gt; 1 km</td>
</tr>
</tbody>
</table>

*The number density of molecules for a temperature of 20 °C

### Thread

<table>
<thead>
<tr>
<th>Thread designation</th>
<th>External diameter in mm</th>
<th>Bead wire diameter</th>
<th>Pitch in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric ISO thread</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M3</td>
<td>3.00</td>
<td>2.5</td>
<td>0.50</td>
</tr>
<tr>
<td>M4</td>
<td>4.00</td>
<td>3.2</td>
<td>0.70</td>
</tr>
<tr>
<td>M5</td>
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Abrasion resistance
The abrasion resistance refers to the resistance of suction pads (elastomer part) against mechanical stress, especially friction. It is determined by the material properties of the suction pad as well as its shape.

Absolute pressure
The absolute pressure refers to the absolute zero point, or a space completely empty of molecules. In an absolute vacuum there is a pressure of 0 bar. A relative vacuum of -600 mbar corresponds to an absolute pressure of 400 mbar.

Air-saving function
Air-saving function refers to the ejector’s air-saving function during the handling procedure. Once the ejector reaches a particular vacuum value, the evacuation process is interrupted. If the vacuum drops below a defined value, the ejector starts evacuating again. The air-saving function can therefore increase the energy and economic efficiency of a vacuum system.

Ambient pressure (atmospheric pressure)
Ambient pressure refers to the hydrostatic pressure that exists at any given point. Ambient pressure is also known as atmospheric pressure. The standard atmospheric pressure at sea level is 1,013 mbar. The ambient pressure drops with increasing altitude. At an altitude of 600 m (the location of J. Schmalz GmbH in Glatten, Germany) the ambient pressure is reduced to 938 mbar. The ambient pressure has a direct influence on the maximum vacuum value that can be reached.

Bernoulli’s principle
Bernoulli’s principle describes the drop in pressure of a fluid when it passes from a narrow section to a much wider section. In practice, this happens in the form of a direct transition into an open space. To prevent the vacuum collapsing, the fluid is diverted to the side.

Centralized vacuum system
In a centralized vacuum system, the vacuum is generated with a central vacuum source for more than one suction pads.

Check valve
The check valve is the valve that automatically monitors volume flow. If the volume flow exceeds a defined value, the valve closes automatically; for example, when suction pads are not being used.

Control pressure range
The control pressure range is the range between the lowest and highest permissible control pressures.

Cycle time
The cycle time refers to the time taken for a repetitive process to complete one cycle.

Decentralized vacuum system
In a decentralized vacuum system, a vacuum is generated directly at each individual vacuum suction pad. Positioning vacuum generation directly at the suction pad allows for short pick-up and depositing times.

Evacuation time
The evacuation time refers to the time it takes to evacuate a certain volume to reach a required vacuum value.

Flow resistance
Flow resistance refers to a reduced flow cross-section in a vacuum line. The resistance reduces the volume flow that can pass through a line.

Friction coefficient
The friction coefficient $\mu$ refers to the relationship between friction force and normal force (contact force between suction pad and workpiece). The friction coefficient is not specified by an unit.

High vacuum
A high vacuum describes any vacuum in which there is an absolute pressure of $10^{-7}$ to $10^{-3}$ mbar. High vacuums are used, for example, in electron tubes and particle accelerators.

Holding force
Holding force refers to the force that can be exerted by a suction pad to grip a workpiece. It is calculated by multiplying the pressure difference by the effective suction area of the suction pad ($F = \Delta p \times A$). The holding force of a suction pad is thus influenced by underpressure and the suction area. It is a theoretical value, specified without safety factors. It is usual to state the holding force of a suction pad with a relative vacuum of 60%.

Hysteresis
Hysteresis refers to a pressure difference between two switching points, and thus defines the state of the output signal. The respective output signal changes when either the upper or lower limit value of the hysteresis is reached. Using the example of a vacuum switch: when the vacuum reaches a specified value, the signal changes to “ON”. If the vacuum drops below a defined value, the signal switches to “OFF”. Hysteresis is mainly used to control the air-saving function of ejectors.

Idle position of NC valve
The Idle position of an NC valve refers to the position of the valve when it is not actuated, i.e. “closed” (normally closed).
Idle position of NO valve
The idle position of an NO valve refers to the position of the valve when it is not actuated, i.e. “open” (normally open).

Inner volume
The inner volume indicates the volume of the body that has to be evacuated during a suction procedure. For example, the inner volume of a suction pad has an effect on the evacuation time.

Leakage
Leakage refers to a leak within the vacuum system. This can be caused by missing or faulty sealing elements, or by the porosity of the workpiece being processed.

Load case
Load case refers to the handling task, or the process of handling a workpiece.
Load case I – Suction pad horizontal, direction of force vertical
Load case II – Suction pad horizontal, direction of force horizontal
Load case III – Suction pad vertical, direction of force vertical

Low vacuum
A low vacuum describes any vacuum in which there is an absolute pressure of 1 mbar up to atmospheric pressure (1,013 mbar). Examples of applications for a low vacuum include light bulbs and vacuum cleaners. Vacuum handling technology also uses values in the low vacuum range because these can be generated economically to create high suction power and short cycle times.

Medium vacuum
A medium vacuum describes any vacuum in which there is an absolute pressure between 0.001 mbar and 1 mbar. Medium vacuums are used, for example, in low-pressure gas-filled lights.

Nominal flow
Nominal flow refers to the maximum flow through a certain diameter (nominal diameter). The nominal flow is given in l/min or m³/h.

Normal force
Normal force is the force component acting perpendicular to a surface. Every force acting on a surface can be divided into normal force and shear force (see “Shear force”). Based on the normal force, the friction force can be calculated using the friction coefficient for a material pairing. The result indicates the friction force between two surfaces, for example between a suction pad and a workpiece. Normal force is measured in Newton [N].

NPN – Switching output
NPN switching output refers to the configuration of a switching output in cases where the load is connected to the positive pole of the operating voltage source. The output transistor of the vacuum switch connects the active device through to the operating voltage, allowing current to flow through the consuming device.

Minimum radius of curvature
The minimum radius of curvature refers to the smallest radius that a suction pad can securely grip. For round suction pads, this refers to a sphere, while for oval suction pads it refers to a cylinder.

Operating temperature
The operating temperature is the temperature range in which a product can be deployed or run.

Overpressure resistance
Overpressure resistance refers to the maximum pressure that a body (for example, a reservoir or vacuum filter) can resist.

PNP Switching output
PNP switching output refers to the configuration of a switching output in cases where the load has a permanent connection to the operating voltage source. The output transistor of the vacuum switch connects the active device to the positive pole, allowing current to flow through the consuming device.

Recovery time
The recovery time is the period in which the product is not being used or is not subject to significant work loads. The product can recover during this time.

Reference pressure
Reference pressure is the pressure referred to by a sensor. Vacuum switches, for example, have a connection for reference air.

Relative pressure
Relative pressure refers to the value of pressure in relation to the prevalent ambient pressure. The vacuum is given using negative values. Relative pressure has a pressure of 0 mbar as a reference point. An absolute pressure of 400 mbar corresponds to a relative pressure of -600 mbar. In the field of vacuum handling, it is also common to state the values in percentages: -600 mbar corresponds to a vacuum of 60%.

Reversing valve
A reversing valve is a type of changeover valve used in a blower. The valve supplies the system alternately with overpressure and underpressure. The valve thus controls the suction, blow-off and neutral setting in the vacuum system.

Shear force
Shear force is the force acting tangentially to a surface and indicates how much friction can be transferred between the suction pad and workpiece. Shear force is given in Newton [N].

Shore hardness
Shore hardness refers to the hardness of elastomers and plastics. It is a standardized material property for the hardness of materials.
Standard liter
A standard liter is the measurement of a gas occupying a liter at 20 °C and 1,013 mbar (standard state).

Standard pressure
Standard pressure is the pressure in the atmosphere under standard conditions. In both technology and the natural sciences, this is 1,013 mbar at 0°C. The values in the Schmalz catalog refer to a temperature of 20 °C.

Standard temperature
Standard temperature is the temperature under standard conditions. The values in the Schmalz catalog refer to a temperature of 20 °C.

Suction force
See “Holding force”

Suction pad stroke
The suction pad stroke refers to the stroke effect that is created by the suction pad when picking up a workpiece. The stroke value indicates the maximum contraction of the suction pad.

Suction power
See “Suction rate”

Suction rate
Suction rate refers to the suction power of a vacuum generator. This value indicates the volume that can be evacuated by a vacuum generator in a certain time. The suction rate is given in l/min or m³/h.

Switching point
The switching point refers to a point at which a switch changes the state of the output signal. If, for example, a programmed vacuum value is reached on a vacuum switch, the output signal switches to “ON” and there is voltage at the switch output. The initial position of the signal can be set to either NC (opener) or NO (closer).

Vacuum
A vacuum is a pressure range lower than that of the ambient pressure. The vacuum value is divided into various classes; refer to “High Vacuum”, “Medium Vacuum” and “Low Vacuum”.

Venturi principle
The Venturi principle describes the correlation between dynamic and static air pressure when air flows through a tube. At the narrowest section, the dynamic pressure is at a maximum, while the static pressure is at a minimum. Since the same volume is flowing through the tube, the velocity increases in proportion to the cross sections. Because of this differential pressure, a vacuum can be created and air can be drawn in by using Venturi nozzles with a side inlet port. Vacuum generators based on this principle are called ejectors.

Volume flow
Volume flow refers to the volume of a medium that flows through a cross section within a certain amount of time. Volume flow is given in l/min or m³/h.

Workpiece temperature
The workpiece temperature is the temperature of a processed workpiece. This temperature can influence the selection of a suitable suction pad material.