Example of Vacuum calculation

**System design - the procedure**

In this section the design procedure is described for a complete system step by step. This exercise is based on a typical design example.

The calculations in the example are based on the following data:

**Workpiece**
- Material: steel sheets, stacked on a pallet
- Surface: smooth, flat, dry
- Dimensions: length: max. 2500 mm, width: max. 1250 mm, thickness: max. 2.5 mm, weight: circa 60 kg

**Handling system**
- System used: portal transfer unit
- Available compressed air supply: 8 bar
- Control voltage: 24 V DC
- Transfer procedure: horizontal - horizontal
- Max. acceleration values: X and Y axes: 5 m/s², Z axis: 5 m/s²
- Cycle time: 30 s
- Planned times: for picking up: <1 s, for releasing: <1 s

**Calculating the weight of the workpiece**

For all subsequent calculations, it is important to know the mass of the workpiece to be handled. This can be calculated with the following formula:

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

where:
- \( m \) = mass [kg]
- \( L \) = length [m]
- \( B \) = width [m]
- \( H \) = height [m]
- \( \rho \) = density [kg/m³]

Example: \( m = 2.5 \times 1.25 \times 0.0025 \times 7850 \)
\[ m = 61.33 \text{ kg} \]

**Forces - how high forces do the suction pads have to support?**

In order to determine the necessary holding forces, the above mass calculation is needed. In addition, the suction pads must be capable of handling the acceleration forces which, in a fully automatic system, are by no means negligible. In order to simplify the calculation, the three most important and most frequent load cases are shown graphically and described below.

**Important:**
In the following simplified representations of the load cases I, II and III, the worst case with the highest theoretical holding force must always be used for the subsequent calculations.
Load case I: horizontal suction pads, vertical force

\[ F_{TH} = \text{theoretical holding force} \ [N] \]
\[ m = \text{mass} \ [kg] \]
\[ g = \text{acceleration due to gravity} \ [9.81 \text{ m/s}^2] \]
\[ a = \text{system acceleration} \ [\text{m/s}^2] \]
\[ S = \text{safety factor} \]
(remember to include the “emergency off” situation!)

\[ S = \begin{cases} 
1.5 & \text{for critical inhomogeneous or porous materials or rough surfaces} \\
2.0 & \text{or higher} 
\end{cases} \]

Example: \[ F_{TH} = 61.33 \times (9.81 + 5) \times 1.5 \]
\[ F_{TH} = 1363 \text{ N} \]

Comparison:
A comparison of the figures for load cases I and II results, in this example, in a maximum value for \( F_{TH} = 1822 \text{ N} \) in load case II, and this value is therefore used for further design calculations.

Load case II: horizontal suction pads, horizontal force

\[ F_{TH} = \text{theoretical holding force} \ [N] \]
\[ F_a = \text{acceleration} = m \times a \]
\[ m = \text{mass} \ [kg] \]
\[ g = \text{acceleration due to gravity} \ [9.81 \text{ m/s}^2] \]
\[ a = \text{system acceleration} \ [\text{m/s}^2] \]
\[ \mu = \text{coeff. of friction}^* = 0.1 \text{ for oily surfaces} \\
= 0.2 \ldots 0.3 \text{ for wet surfaces} \\
= 0.5 \text{ for wood, metal, glass, stones, ...} \\
= 0.6 \text{ for rough surfaces} \]

\[ S = \text{safety factor} \]
(average minimum value 1.5;
for critical inhomogeneous or porous materials or rough surfaces 2.0 or higher)

Example: \[ F_{TH} = 61.33 \times (9.81 + 5/0.5) \times 1.5 \]
\[ F_{TH} = 1822 \text{ N} \]

For the example used for this description, load case III can be ignored, since the workpieces are to be handled only in a horizontal orientation.

Load case III: vertical suction pads, vertical force

\[ F_{TH} = \left( \frac{m}{\mu} \right) \times (g + a) \times S \]
\[ F_{TH} = \text{theoretical holding force} \ [N] \]
\[ m = \text{mass} \ [kg] \]
\[ g = \text{acceleration due to gravity} \ [9.81 \text{ m/s}^2] \]
\[ a = \text{system acceleration} \ [\text{m/s}^2] \]
\[ \mu = \text{coeff. of friction} \]
(remember to include the “emergency off” situation!)

\[ \mu = \begin{cases} 
0.1 & \text{for oily surfaces} \\
0.2 \ldots 0.3 & \text{for wet surfaces} \\
0.5 & \text{for wood, metal, glass, stones, ...} \\
0.6 & \text{for rough surfaces} \end{cases} \]

\[ S = \text{safety factor} \]
(average minimum value 2;
higher for critical, inhomogeneous or porous materials or rough surfaces)

Example: \[ F_{TH} = 61.33 \times (9.81 + 5/0.5) \times 1.5 \]
\[ F_{TH} = 1822 \text{ N} \]

Comparison:
A comparison of the figures for load cases I and II results, in this example, in a maximum value for \( F_{TH} = 1822 \text{ N} \) in load case II, and this value is therefore used for further design calculations.
How to select the suction pads

The suction pads are normally selected on the basis of the following criteria:

Operating conditions: the operating conditions (single or multiple shift operation, expected lifetime, aggressive surroundings, temperature etc.) at the point of use are decisive for the selection of the suction pads.

For the selection of the vacuum pad material in relation to the type of work piece to handle, see the table shown in the end of the vacuum pad section.

Surface: depending on the surface of the handled workpieces, certain suction-pad versions may be more suitable. The product range includes flat and bellows suction pads.

Example:
In this example, where steel sheets are to be handled, we will use the flat suction pads, Mod. VTCF in NBR. This is the best and most efficient solution for the handling of smooth, flat workpieces.

Calculation of the suction force \( F_s \) [N]

\[
F_s = \frac{F_{th}}{n}
\]

\( F_s \) = suction force

\( F_{th} \) = theoretical force

\( n \) = number of suction pads

Example:
For medium sized (2500 x 1250 mm) steel sheets, normally 6 to 8 suction pads would be used. The most important criterion for deciding the number of suction pads in this example, is the flexing of the steel sheet during transport.

According to the Technical Data as shown on section a/3.07_01 for Series VTCF, 6 pcs. of suction pads Mod. VTCF-950N are needed with a suction force of 340 N each.

We decide to use: Spring plunger NPM-FM-1/4-75
We need the largest possible stroke to cope with the hanging ends of the steel sheets. The 1/4 thread is needed for connection to the flexible nipple.

Flexible nipple Mod. NPF
Optimum flexibility for inclined workpiece surfaces.

Check valves Mod. VNV
These are used on vacuum gripper systems containing multiple suction pads in order to shut off individual suction pads which are not covered by the workpiece, (when handling work pieces of different sizes).

Note:
When selecting the mounting elements, please make sure that these can be screwed onto the suction pads, i.e. that they have threads of the same size. Also note the load-carrying capacities of the mounting elements.

Selection of the mounting elements

Normally, the manner in which the suction pads are mounted is defined to meet the customer’s needs. However, there may be special reasons which make a specific mounting element mandatory in certain cases:

Uneven or sloping surfaces
The suction pad must be able to adapt itself to the slope:
- flexible nipple NPF

Different heights or thicknesses
The suction pads must be spring-mounted in order to compensate for varying heights:
- spring plunger NPM-NPR

Example:
In this example the steel sheets are stacked on a pallet. If the sheets are larger than the pallet, they may hang down at the ends. This means that the suction pads must be able to compensate for considerable height differences and slope angles.

Selection of vacuum hoses

The size of the vacuum hose should match the suction pads which are used. For the selection of the suitable tube dimensions, see recommendations under Technical Data.

Example:
For example, from the table with Technical Data we choose a TRN 8/6 hose in polyamide.
Calculation vacuum generators

Based upon our experience and upon the values measured during the system design, we recommend to choose the vacuum generator depending on the diameter of the suction pad, according to the table below:

Note:
The indicated values apply to all types of vacuum generators. The recommended suction rate is for a single suction pad and is valid only for smooth, airtight surfaces. For porous surfaces we recommend the execution of a suitable test before the selection of the vacuum generator.

Calculation of the required suction rate $V$ [M³/H, L/MIN]

$$V = n \times V_s$$
$$n = \text{number of suction pads}$$
$$V_s = \text{required suction rate for a single suction pad} \ [\text{m}^3/\text{h}, \text{l/min}]$$

The suction rate values of the different vacuum generators can be found in the table Technical Data.

<table>
<thead>
<tr>
<th>Suction pad Ø (mm)</th>
<th>Required suction rate Vs</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 20</td>
<td>0.17 m³/h</td>
</tr>
<tr>
<td>up to 40</td>
<td>0.35 m³/h</td>
</tr>
<tr>
<td>up to 60</td>
<td>0.5 m³/h</td>
</tr>
<tr>
<td>up to 90</td>
<td>0.75 m³/h</td>
</tr>
<tr>
<td>up to 120</td>
<td>1.0 m³/h</td>
</tr>
</tbody>
</table>

Example: $V = 6 \times 16.6$  
$V = 99.6$ l/min

We choose a compact ejector Mod. VEC-20 with a suction rate of 116 l/min.

Selection of vacuum switches

Vacuum switches and pressure gauges are normally selected on the basis of the functions required in the application and on the switching frequency. The following functions are available:
- adjustable switching point
- fixed or adjustable hysteresis
- digital and/or analog output signals
- status LED
- display with keypad
- connection with M5 Female thread, G1/8 Male flange or plug-in tube

Example:
- vacuum switch SWD-V00-PA with digital display, adjustable switching point and adjustable hysteresis (already integrated in the compact ejector)
- pressure gauge.

Selection of the vacuum switches and pressure gauges

Even if you are confident that the results of the system-design work are correct, you should still carry out tests with original workpieces to be on the safe side. However, the theoretical system design will give you a good idea of the general parameters for the intended application.
Technical information about suction pads

When designing a vacuum circuit and selecting suitable suction pads it is necessary to follow certain calculations to select each individual component in a correct way. Listed below is a summary of the most common data to take into consideration.

### Technical information

**Lateral force**
The measured value in N at a vacuum of -0.6 bar on a dry or oily, flat and smooth workpiece surface. These values do not include a safety factor.

**Minimum workpiece curvature radius**
This specifies the minimum radius at which the workpiece can be gripped securely by the suction pad.

**Theoretical suction force**
Theoretical force (N) at a -0.6 bar measured at sea level. Since this is a theoretical value, it is necessary to reduce this value by adding a safety factor to compensate for friction or loss of vacuum, depending on the application (from rough workpiece surface or porous material etc.)

**Internal volume**
This is used to calculate the total volume of the gripper system. With this value, it is also possible to calculate the evacuation time.

**Suction pad stroke**
This is the lifting effect which occurs during evacuation of a bellows type suction pad.

### Suction pad material selection

<table>
<thead>
<tr>
<th>Applications</th>
<th>NBR</th>
<th>SI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Oily parts</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Slight marking of workpieces</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>For high temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>For low temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Very smooth surfaces (glass)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Very rough surfaces (wood, stone)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
### Selection and configuration

#### Planning check-list for selection of suction pads

<table>
<thead>
<tr>
<th>Question</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>What are the workpiece dimensions and weight?</td>
<td>This is important data for the suction force calculation and to establish the required suction force and number of suction pads (see technical information).</td>
</tr>
<tr>
<td>How is the workpiece surface (rough, structured, smooth)?</td>
<td>It determines the kind of suction pad (material, shape, dimensions).</td>
</tr>
<tr>
<td>Could the workpiece be dirty?</td>
<td>This is important information to select the suction pad dimensioning (see technical information) and also for the design of the dust filter.</td>
</tr>
<tr>
<td>If so, what kind of dirt?</td>
<td></td>
</tr>
<tr>
<td>What is the highest workpiece temperature?</td>
<td>Temperature is important to select the suction pad material.</td>
</tr>
<tr>
<td>Is an accurate gripping/placing/positioning required?</td>
<td>Determines the structure, the type and the version of the suction pad.</td>
</tr>
<tr>
<td>What is the cycle time?</td>
<td>This data is important for the dimensioning and plays a part in the calculations (for instance the vacuum generator suction capacity calculation); (see the technical information).</td>
</tr>
<tr>
<td>What is the maximum acceleration during handling?</td>
<td>This is important for the dimensioning and design of the suction force, together with the related calculations (for instance the suction capacity and the moment of inertia); (see the techn. inf.).</td>
</tr>
<tr>
<td>Which kind of handling is needed (moving, slewing, turning over)?</td>
<td>This data is important to establish the dimension and the suction force calculation.</td>
</tr>
</tbody>
</table>

### Materials summary

<table>
<thead>
<tr>
<th>Chemical designation</th>
<th>Nitrile rubber</th>
<th>Silicone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviation</td>
<td>NBR</td>
<td>SI</td>
</tr>
<tr>
<td>Wear resistance</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>Resistance to permanent deformations</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>General weather resistance</td>
<td>**</td>
<td>***</td>
</tr>
<tr>
<td>Resistance to ozone</td>
<td>*</td>
<td>****</td>
</tr>
<tr>
<td>Resistance to oil</td>
<td>****</td>
<td>*</td>
</tr>
<tr>
<td>Resistance to fuels</td>
<td>**</td>
<td>*</td>
</tr>
<tr>
<td>Resistance to alcohol, ethanol 96 %</td>
<td>****</td>
<td>****</td>
</tr>
<tr>
<td>Resistance to solvents</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>General resistance to acids</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Resistance to steam</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Abrasion value in mm/s, DIN 53516 (approx.)</td>
<td>100-120 at 60 Sh.</td>
<td>180-200 at 55 Sh.</td>
</tr>
<tr>
<td>Specific resistance [ohm * cm]</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Short-term temperature resistance in °C</td>
<td>from -30° to +120°</td>
<td>from -60° to +250°</td>
</tr>
<tr>
<td>Long-term temperature resistance in °C</td>
<td>from -10° to +70°</td>
<td>from -30° to +200°</td>
</tr>
<tr>
<td>Shore hardness to DIN 53505</td>
<td>from 40 to 90</td>
<td>from 30 to 85*</td>
</tr>
<tr>
<td>Colour/Coding</td>
<td>black</td>
<td>white</td>
</tr>
</tbody>
</table>

* After-bake of silicone 10 h/160 °C = +5 ...10 Shore A

**** excellent  *** very good  ** good  * poor to satisfactory