

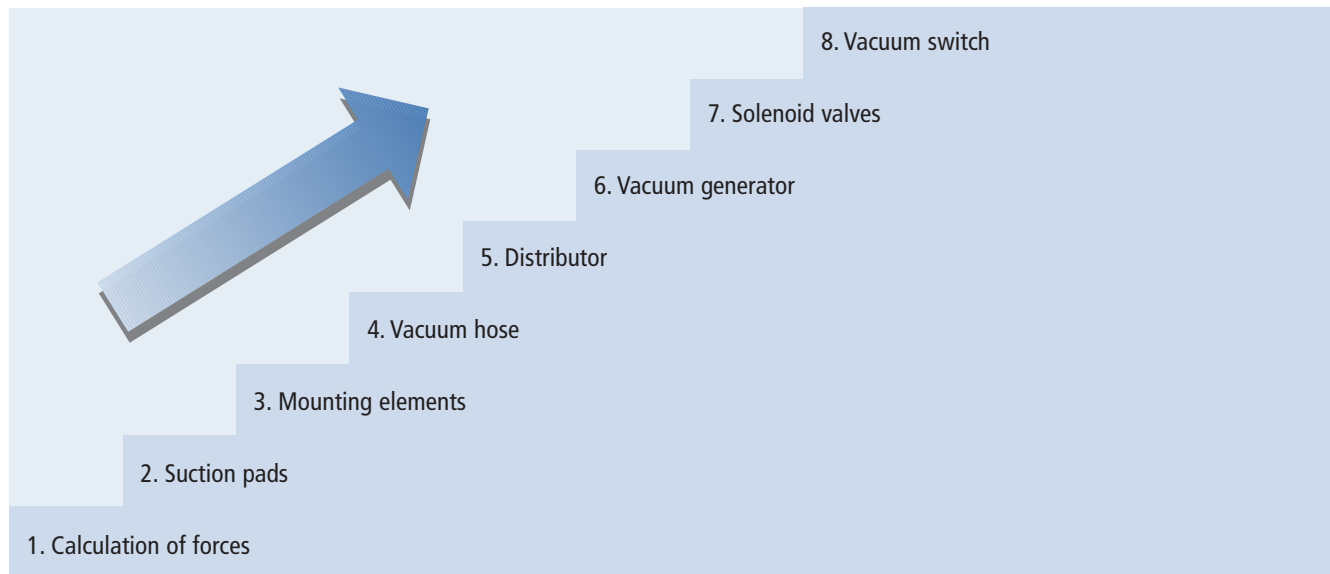
## System design

Calculation examples

### System design procedure

Here, we describe the design procedure for a complete system step by step. In order to make this easier to understand, we have based this system design on a typical example.

A useful tool for the necessary calculations during system design is the Schmalz VacuCalculator, which you can download free of charge from [www.schmalz.com](http://www.schmalz.com).



Flowchart for system design

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: approx. 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/s <sup>2</sup>
	Z axis: 5 m/s <sup>2</sup>
Cycle time:	30 s
Planned times:	for picking up: <1s
	for releasing: <1s

### What does your workpiece weigh?

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:

$$\text{Mass } m \text{ [kg]: } m = L \times W \times H \times \rho$$

L = length [m]

W = width [m]

H = height [m]

$\rho$  = density [kg/m<sup>3</sup>]

$$\begin{aligned} \text{Example: } m &= 2.5 \times 1.25 \times 0.0025 \times 7850 \\ m &= 61.33 \text{ kg} \end{aligned}$$

### Forces – how much do the suction pads have to support?

In order to determine the necessary holding forces, we need the mass calculated above. 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 – suction pads horizontal, force vertical

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

$F_{TH}$  = theoretical holding force [N]

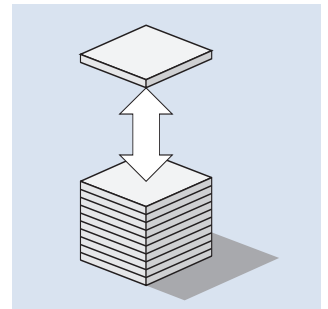
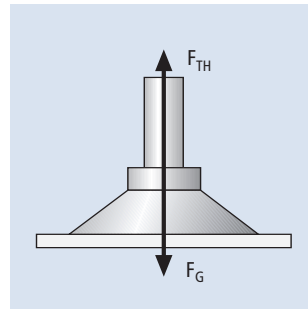
m = mass [kg]

g = acceleration due to gravity [9.81 m/s<sup>2</sup>]

a = system acceleration [m/s<sup>2</sup>]

(remember to include the "emergency off" situation!)

S = safety factor (minimum value 1.5; for critical, inhomogeneous or porous materials or rough surfaces 2.0 or higher)



$$\begin{aligned} \text{Example: } F_{TH} &= 61.33 \times (9.81 + 5) \times 1.5 \\ F_{TH} &= 1363 \text{ N} \end{aligned}$$

The suction pads are placed on a horizontal workpiece which is to be lifted vertically.

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### Load case II – suction pads horizontal, force horizontal

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

$F_{TH}$  = theoretical holding force [N]

$F_a$  = acceleration force =  $m \cdot a$

$m$  = mass [kg]

$g$  = acceleration due to gravity [9.81 m/s<sup>2</sup>]

$a$  = system acceleration [m/s<sup>2</sup>]  
(remember to include the "emergency off" situation)

$\mu$  = coefficient of friction:

= 0.1 for oily surfaces

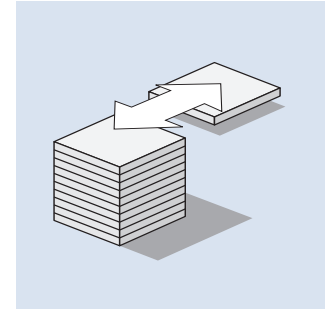
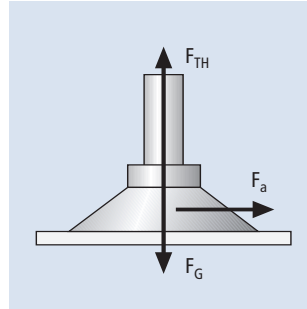
= 0.2 . . . 0.3 for wet surfaces

= 0.5 for wood, metal, glass, stones, ...

= 0.6 for rough surfaces

Caution! The coefficients of friction shown above are average values. The actual values for the workpiece to be handled must be determined by testing!

$S$  = safety factor (minimum value 1.5; for critical, inhomogeneous or porous materials or rough surfaces 2.0 or higher)



The suction pads are placed on a horizontal workpiece which is to be moved laterally.

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

### Load case III – suction pads vertical, force vertical

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

$F_{TH}$  = theoretical holding force [N]

$m$  = mass [kg]

$g$  = acceleration due to gravity [9.81 m/s<sup>2</sup>]

$a$  = system acceleration [m/s<sup>2</sup>]  
(remember to include the "emergency off" situation)

$\mu$  = coefficient of friction:

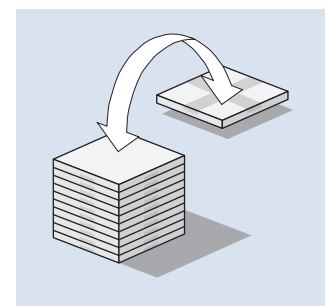
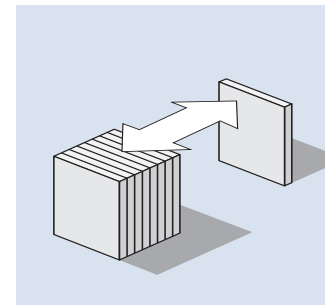
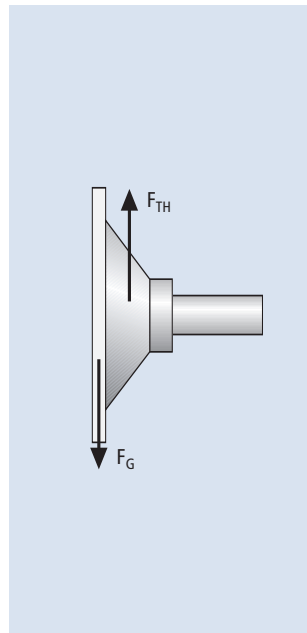
= 0.1 for oily surfaces

= 0.2 . . . 0.3 for wet surfaces

= 0.5 for wood, metal, glass, stones, ...

= 0.6 for rough surfaces

$S$  = safety factor (minimum value 2.0; higher for critical, inhomogeneous or porous materials or rough surfaces)



The suction pads are placed on a vertical or horizontal workpieces which is to be moved vertically or turned to the other orientation.

**Example:**  $F_{TH} = (61.33/0.5) \times (9.81 + 5) \times 2$   
 $F_{TH} = 3633 \text{ N}$

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.

#### Comparison:

A comparison of the figures for load cases I and II results, in this example, in a maximum value for  $F_{TH}$  of **1822 N** in load case II, and this value is therefore used for further design calculations.

### Selection of 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.

**Material:** suction pads made of various materials are available to meet the requirements of the application. Some of these are particularly suitable for smooth or rough surfaces, oily surfaces or easily damaged workpieces. There are also special antistatic suction pads for the handling of electronic components and suction pads which cause little marking of plastic parts etc. Please select the best material for the suction pads from the detailed tables in Section 2.



**Surface:** depending on the surface of the workpieces to be handled, certain suction-pad versions may be more suitable. The product range includes flat and bellows suction pads with many types of sealing lips and sealing edges, which are available in a wide range of sizes and shapes. For an overview of the various suction pad types and their precise advantages, see Section 2.

**Example:** In this example, where steel sheets are to be handled, we will use the flat suction pads of the type PFYN/PFG, made of Perbunan NBR. This is the best and cheapest solution for the handling of smooth, flat workpieces. The data for this suction-pad type can be found on the related pages in Section 2.

#### Calculation of the suction force $F_S$ [N]

$$F_S = F_{TH} / n$$

$F_S$  = suction force

$F_{TH}$  = theoretical holding force

$n$  = number of suction pads

#### Example:

For medium-sized (2500 x 1250 mm) steel sheets, it is normal to use 6 or 8 suction pads. The most important criterion for the number of suction pads in this example, is the flexing of the steel sheet during transport.

$$F_S = 1822/6$$

$$F_S = 304 \text{ N}$$

According to the "technical data" for the suction pad PFYN/PFG (see Section 2), 6 PFYN/PFG 95 NBR suction pads with a suction force of 350 N each are needed.

$$F_S = 1822/8$$

$$F_S = 228 \text{ N}$$

According to the "technical data" for the suction pad PFYN/PFG (see Section 2), 8 PFYN/PFG 80 NBR suction pads with a suction force of 260 N each are needed.

In this example, we decide to use 6 PFYN 95 NBR suction pads, since this number is sufficient and helps to keep the costs down.

#### Important:

- The load each suction pad can carry is shown in the table "technical data" for each suction-pad type in Section 2.
- The load-carrying capacity of the suction pad must always be greater than the calculated value!

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### Selection of the mounting elements

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

#### Uneven or sloping surfaces

The suction pad must be able to adapt itself to the slope:

> **flexible mounting**

#### Differing heights or thicknesses

The suction pads must be spring-mounted in order to compensate for varying heights:

> **spring plunger**



#### 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 greater height differences and slope angles.

In this case, we decide to use:

#### Spring plungers FSTE 1/4" with 75 mm stroke

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 selected flexible mounting element Flexolink FLK.

#### Flexible mounting element Flexolink FLK 1/4" – 1/4" female thread

Optimum flexibility of the suction pad for sloping workpiece surfaces.

#### Note:

When selecting the mounting elements, take care 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. The various mounting elements and their technical data can be found in Section 4.

### Selection of the vacuum hoses

The size of the vacuum hose must match the suction pads being used. Recommendations for the cross-sectional size of the vacuum hose can be found in the table "technical data" in Section 2. The various types and sizes of hoses are shown in Section 8.

#### Example:

For our example, the above-mentioned table "technical data" recommends a vacuum hose VSL 8/6 with an internal diameter of 6 mm.



### Selection of the distributor

The distributor must be selected to match the selected hose size and the number of suction pads.

**Example:**

In our example, the following components are used:

- Hose sleeve ST-1/4 " -8 for the above-mentioned hose VSL 8/6 with an internal diameter of 6 mm and a 1/4" thread
- Distributor VTR 9-1/4" with a 1/4" thread, 9 inputs and one output
- The open inputs must be sealed with three sealing screws VRS-SB 1/4"



### Selection of the vacuum generator

The design of the vacuum generator to be used (ejector, pump or blower) depends on various factors:

- type of material: porous or air-tight
- available power supply: electricity or compressed-air
- restrictions with respect to the size and weight
- compliance with the required cycle times:
  - ejector for short cycle times
  - pump or blower for long distances between the vacuum generator and the suction pads



Selection table for generator type by application								
	materials		cycle times		power supply		transport path	
	air-tight	po-rous	very short <0,5sec	short >0,5sec	compr. air	elec-tricity	short	long
<b>Ejector</b>	X		X		X		X	(X)*
<b>Pump</b>	X			X		X		X
<b>Blower</b>		X		X		X		X

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

**Example:**

In order to achieve the required short gripping and release times, the vacuum should be generated with an ejector, particularly since the workpiece material is air-tight.

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### Calculation of the vacuum generator size

On the basis of our empirical and measured values for system design, we recommend the use of a vacuum generator for the selected suction pad diameters as shown in the following table:

Suction capacity as a function of suction-pad diameter		
Suction-pad Ø	Suction capacity $V_s$	
Up to 60 mm	0.5 m <sup>3</sup> /h	8.3 l/min
Up to 120 mm	1.0 m <sup>3</sup> /h	16.6 l/min
Up to 215 mm	2.0 m <sup>3</sup> /h	33.3 l/min
Up to 450 mm	4.0 m <sup>3</sup> /h	66.6 l/min

#### Note:

The values specified here apply to all types of vacuum generators. The recommended suction capacity is for a single suction pad and is valid only for smooth, air-tight surfaces!

For porous surfaces, we recommend the execution of a suitable test before selection of the vacuum generator.



#### Calculation of the required suction capacity $V$ [m<sup>3</sup>/h, l/min]

$$V = n \times V_s$$

$n$  = number of suction pads

$V_s$  = required suction capacity for a single suction pad [m<sup>3</sup>/h, l/min]

The suction-capacity values of the various vacuum generators can be found in the table "technical data" for each vacuum generator in Section 5.

**Example:  $V = 6 \times 15$   
 $V = 90$  l/min**

In this case, we decide to use the compact ejector SCP 20, which has a suction capacity of 116 l/min.

### Selection of the solenoid valves

Solenoid valves are needed only if we do not use a compact ejector with integrated valves. In order to build a complete vacuum circuit, solenoid valves are needed to control the functions "grip" (vacuum on) and "release" (vacuum off). They are normally used in vacuum circuits where a pump or blower is used to generate the vacuum.

The selection criteria for the solenoid valves are:

- the suction capacity of the vacuum generator
- the available control voltage
- the required operating mode of the solenoid valve (NO/NC)

The nominal flow rate of the selected solenoid valve must always be at least equal to the suction capacity of the vacuum generator.



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### Calculation of the nominal size of the solenoid valve [m<sup>3</sup>/h, l/min]

$$V_V = V_{VE}$$

$V_V$  = nominal flow rate of the solenoid valve [m<sup>3</sup>/h, l/min]

$V_{VE}$  = suction capacity of the selected vacuum generator  
[m<sup>3</sup>/h, l/min]

The nominal flow rates of the various solenoid valves can be found in the table "technical data" for each valve in Section 6. The suction capacity of the vacuum generator is shown in the table, "technical data" for each vacuum generator in Section 5.

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

Here, we can use a solenoid valve of the type EMV-10 with a nominal flow rate of 20 m<sup>3</sup>/h.

#### Note:

Since we have selected a compact ejector SCP 20 (which has integrated valves) in the previous step, no separate valves are needed in this example.

## Selection of the vacuum switches and manometers

Vacuum switches and manometers 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 analogue output signals
- status LED
- display with input keypad
- vacuum connection with M5 female thread, flange or plug-in tube
- supply-voltage and signal connections via cable or M8 screw-in connector

The various versions and their technical data can be found in Section 7.

#### Example:

- Vacuum switch VS-V-D-PNP with digital display, adjustable switching point and adjustable hysteresis (already integrated into the compact ejector)
- Manometer VAM 63/1U



## System design

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### Calculation of the evacuation times

For the subsequent calculations, it is first necessary to determine the total volume to be evacuated  $V_G$ .

$$V_G = V_1 + V_2 + V_3 + V_4 + V_5 + \dots$$

$V_1$  = volume of the suction pads [m<sup>3</sup>]

$V_2$  = volume of the mounting elements [m<sup>3</sup>]

$V_3$  = volume of the vacuum hoses [m<sup>3</sup>]

$V_4$  = volume of the distributor [m<sup>3</sup>]

$V_5$  = volume of the filter (if necessary) [m<sup>3</sup>]

$V_6$  = volume of the solenoid valve (if necessary) [m<sup>3</sup>]

...

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

### Calculation of the evacuation time $t$ [h]

$$t = (V_G \times \ln(P_a/P_e) \times 1.3) / V$$

$V_G$  = volume to be evacuated [m<sup>3</sup>]

$\ln$  = natural logarithm

$P_a$  = initial absolute pressure [1013 mbar]

$P_e$  = final absolute pressure [mbar]

$V$  = suction capacity of the vacuum generator [m<sup>3</sup>/h]

Example:

$$t = (0.000546 \times \ln(1013/400) \times 1.3) / 6.95$$

$$t = 0.0000949 \text{ h} = 0.34 \text{ sec}$$

60% = 400 mbar absolute

The results show that we can construct an economical solution for a complete system from the Schmalz vacuum components and that the Schmalz product range offers all necessary components for a well-designed system which operates reliably.

### Summary

Even if you are confident that the results of the system-design 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.