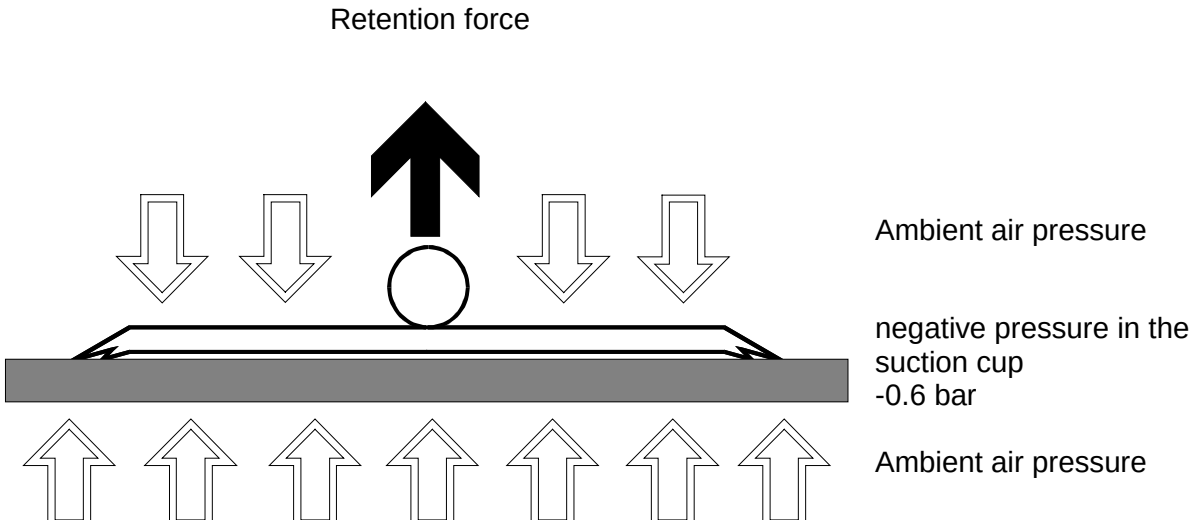
Basic knowledge

Why do vacuum lifting devices lift anything at all?

Ambient air pressure exerts its force on everything in our immediate environment.



How high is .'normal' air pressure?

At sea level, it measures about 1013 mbar.

The higher we rise above sea level, the lower the ambient air pressure becomes.

If we were now to place a suction cup on a surface, e.g. a panel, the air pressure would be exerted externally on the suction cup and on the panel. Once the interior of the suction cup has been connected to its immediate environment by an aperture (connection), the same air pressure applies inside as outside. The suction cup can be moved and does not gain any adhesion while the internal and external air pressure levels are identical.

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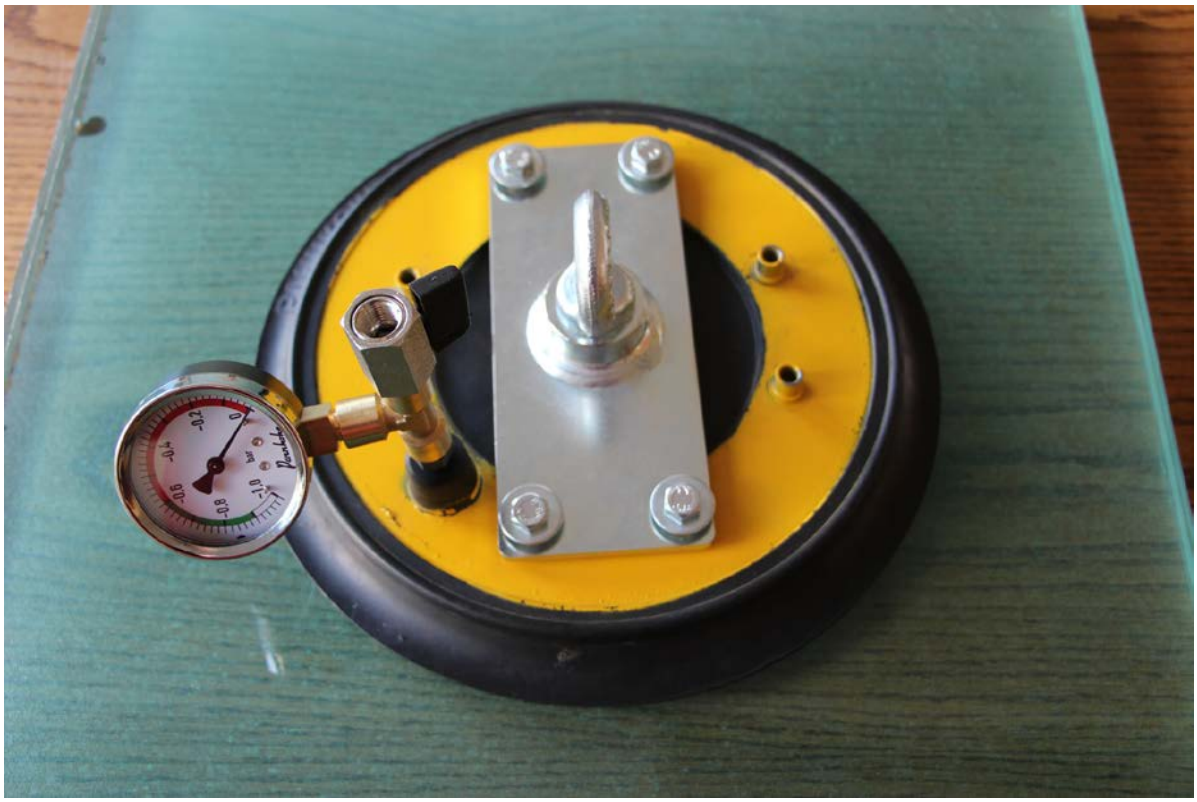
Test equipment:

A suction cup equipped with vacuum meter, vent valve and hose nipple.

A clean, smooth pane of glass



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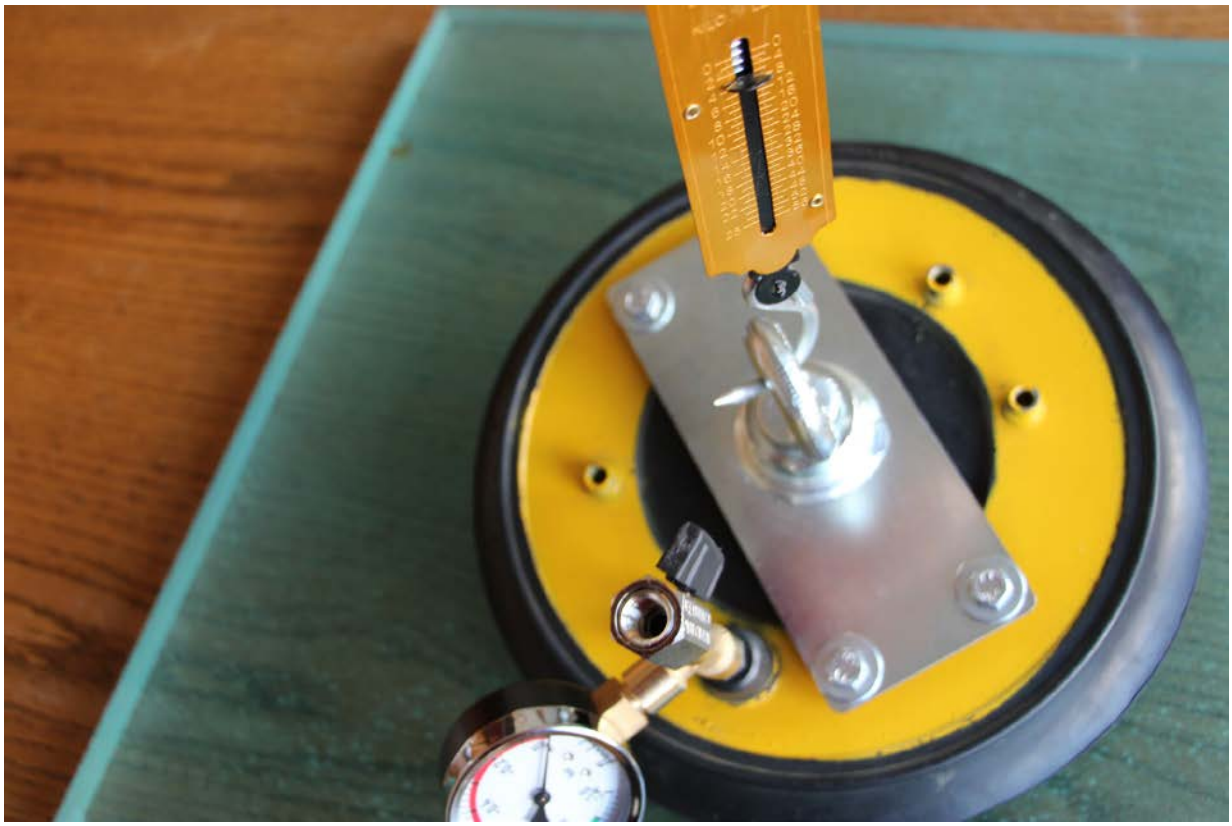
Test:

Place a suction cup with opened vent valve on a glass surface and move it around.



Place a suction cup with closed vent valve (no pressure appleid) on a glass surface and move it around.

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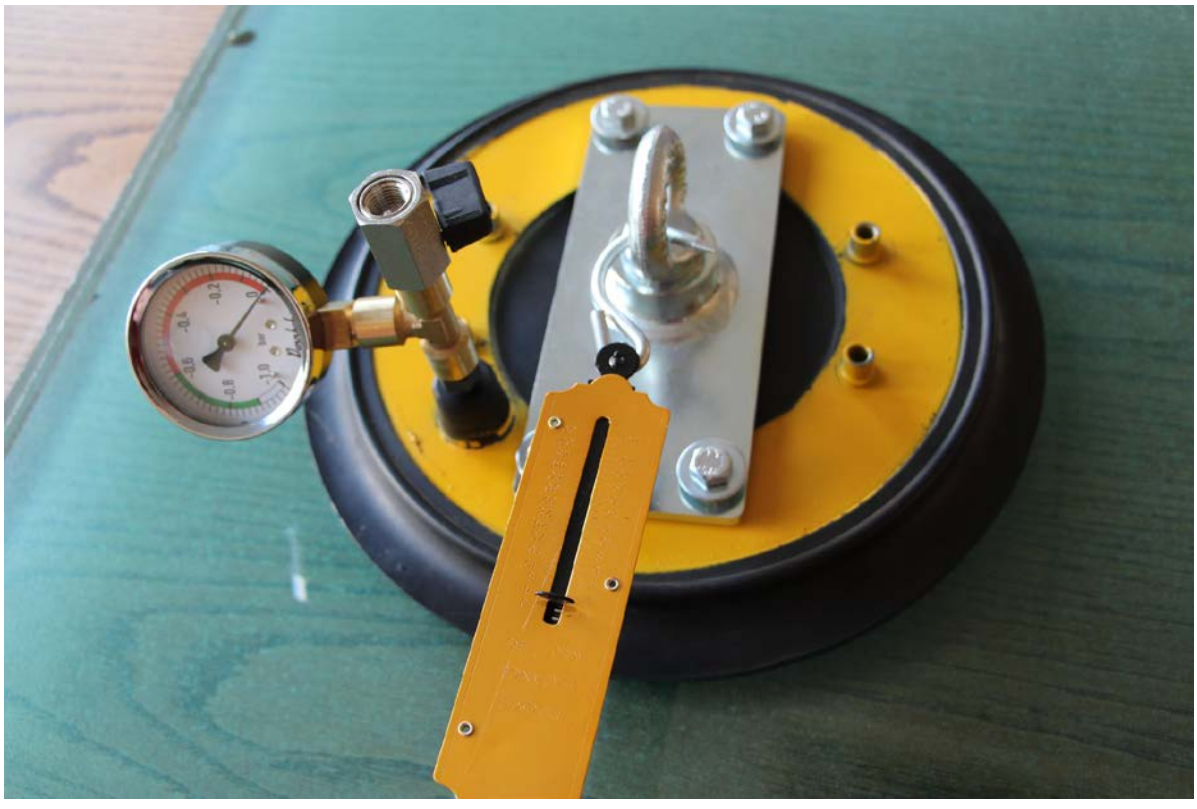
Place a suction cup with closed vent valve (no pressure applied) on a glass surface and move it around.



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The ambient air pressure presses the suction cup onto the surface and the surface onto the suction cup. The greater the difference in pressure between the interior space and the ambient air pressure, the greater is the contact pressure exerted on this surface area.

This creates a kind of connection between the two parts and it can be lifted, moved or held in position.

When this pressure differential ceases to exist, the two parts separate from one another again.

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What influence does height above sea level have on carrying capacity?

Ambient air pressure declines as you gain height above sea level when working with this device. The pressure differential between the ambient air pressure and the vacuum inside the suction cup reduces.

Here is a small table that gives you a reference point for this.

Dependence on the air pressure at various altitudes (Norm atmoshere)	
Altitude in meters	air pressure in mbar
0	1013.25
100	1001.3
200	989.5
400	966.1
600	943,2
800	920.8
1000	898,8
1200	877.2
1400	856,0
1600	835.3
1800	814.9
2000	795.0

This in turn has a negative impact on the carrying capacity of the vacuum lifting device.

As a general rule, vacuum lifting devices operate at a differential pressure of -0.6 bar. In particular, battery-powered devices have a vacuum pump with a lower vacuum rating. On devices of this kind, the cutout will fail at some point, once at a sufficiently high altitude.

We have conducted tests that demonstrate that standard devices, at a height above sea level of 1000 metres have no problem with the lower ambient air pressure. Thereafter, it can get difficult.

For a special application, we manufactured a vacuum lifting device for a company trading as Ruch in Switzerland. Even at an altitude of 3000 metres, this device can move loads of up to 2000 kg safely, and can even do so if one of its vacuum circuits should fail, enabling it to comply with EU standard EN 13155.

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What influence does the size of suction cup have on carrying capacity?

The holding force of a suction cup is not only dependent on the differential pressure between ambient air pressure and the vacuum inside the suction cup, but instead also on the surface area of the suction cup.

The contact pressure of the ambient air pressure acts on the surface. As a consequence:

The larger the effective surface area, the greater the retaining force.

Although the design of the suction cup has a role to play here, the choice of material and other factors are more significant, but essentially a large suction cup can support greater loads than a small one.

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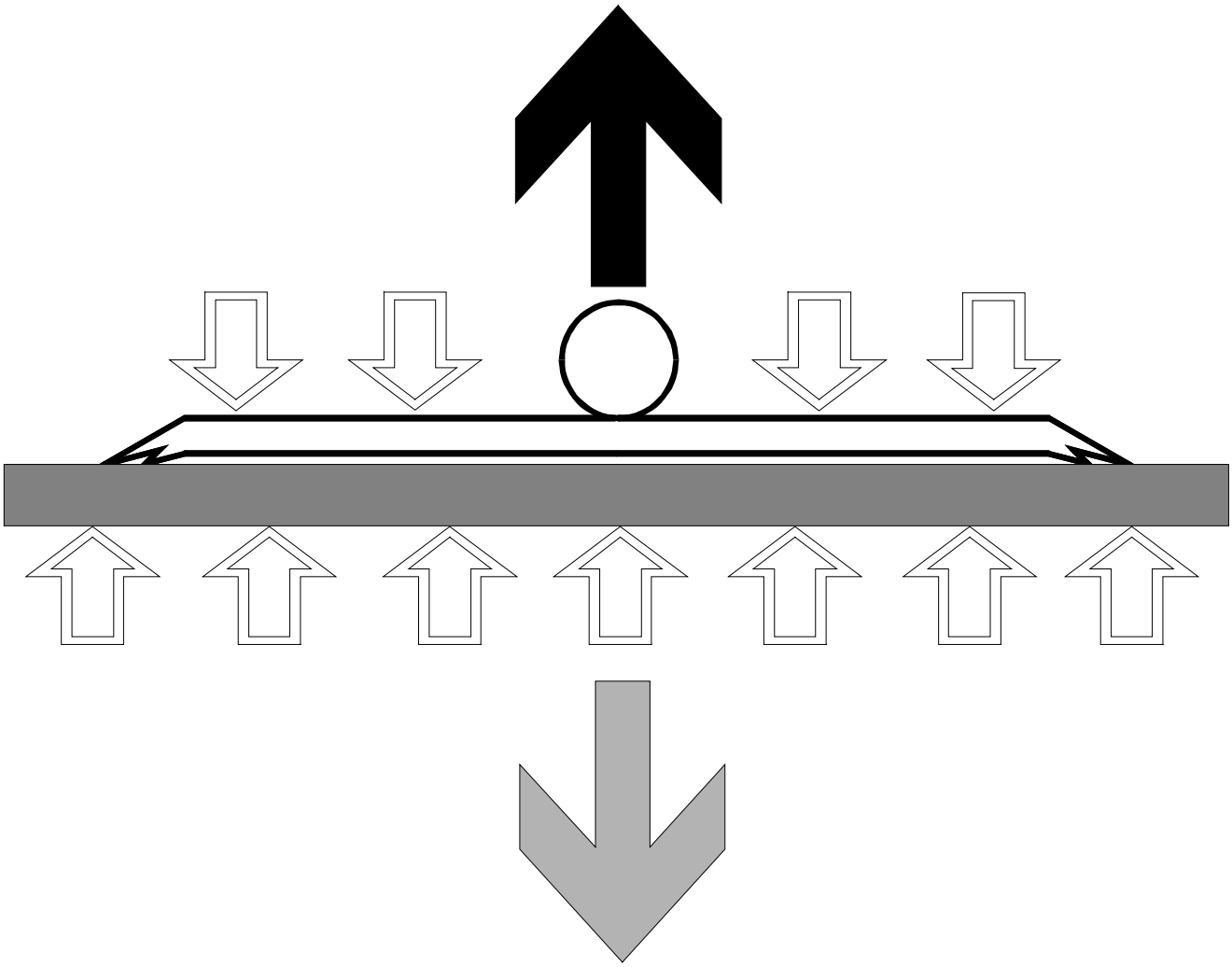
What is the difference between horizontal and vertical operation with a vacuum lifting device?

In the case of a horizontal load, a force is applied to the suction cup that acts at right angles to the suction cup surface area. In the event of an overload, the suction cup will be torn away from the surface.



The retaining force is calculated as follows: Product = surface x pressure differential. If this value is exceeded the suction cup pulls-off and this is called the pull-off power.

If the suction cup is dimensionally stable, the carrying capacity in this case is easy to calculate and it also does not deviate much from the theoretical value during tensile tests.

An investigation by the technical college in Kiel has shown us that, at an angle of inclination of more than 10° from a horizontal position, a friction coefficient for sliding off needs to be taken into account.

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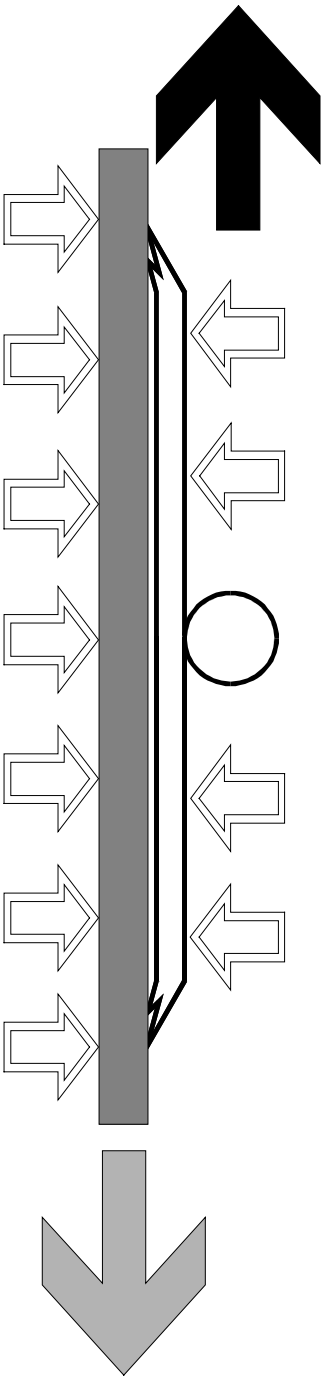
In the perpendicular load scenario, the suction cup is subject to a force that acts parallel to the surface of the suction cup. In the event of an overload, the suction cup would slide off the surface. Here, friction between suction cup surface and the material being transported is the defining factor for the carrying capacity of the suction cup.



In general, the retention force is essentially lower in a vertical direction than in a horizontal one. If this retention force is exceeded, the suction cups slip off slowly. This is called the slipping off force.

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Which factors affect the carrying capacity of a suction cup?

- Surface of the suction cup
- Differential pressure
- Humidity
- Contamination of the suction cups
- Contamination of the material
- Separating agent
- Altitude when in use
- Surface properties of the material
- Air permeability of the material
- Environmental temperature
- Temperature of the material
- Bending stiffness of the material

Please note:

Any damage to the suction lip or sealing lip reduces the load capacity .

Any contamination of the surface reduces the load capacity .

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What influence does the surface area of the suction cup have on its carrying capacity?

The larger the surface area, the greater the carrying capacity (in theory). Since the diameter is included in the calculation of the surface area as a quadratic function, any change in diameter has an extreme impact on carrying capacity.

Test:
Test with suction cups with identical layout but different diameters.

What influence does the level of vacuum have on the carrying capacity of the suction cup?

The higher the differential pressure between ambient air pressure and pressure in the sealed suction cup, the higher the carrying capacity.

Test:
Test of suction cup 540 / 388 with different levels of vacuum

What influence does humidity have on the carrying capacity of the suction cup?

Humidity between rubber and glass pane generally reduces the friction factor. This substantially reduces the carrying capacity, depending on suction cup version. Unfortunately, no simple test can be carried out because precise determination of humidity and its distribution across the surface of the glass pane is difficult to reproduce. For a comparison measurement, reproducibility must be assured, then information must be provided to the operator in a simple way to enable the operator to get on with the job.

The word 'dry' is not an ambiguous term, and is easy to check for.

For safety reasons, if glass panes are damp or wet, assume a 50% reduction in carrying capacity.

The friction coefficient changes in response to humidity.

Test:
Test of suction cup 540 / 388, dry and dampened suction surface / panel

Avoid entraining water into the vacuum system since this can cause malfucntions under certain circumstances. Even water separators do not provide full protection for the vacuum system.

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Safety Factors

The safety factor 2 has been set as the new standard by the European Standard EN 13155 for the slipping off force as well as for the pull-off force. For the slipping off force one must consider the coefficient of sliding friction **μ**.

How is carrying capacity calculated?

$$\text{horizontal load capacity} = \frac{\text{effective surface} \times \text{effective vacuum}}{\text{safety factor}}$$

$$\text{vertical load capacity} = \frac{\text{effective surface} \times \text{effective vacuum} \times \text{coefficient of friction}}{\text{safety factor}}$$

Note:

Without friction, nothing can be lifted vertically.

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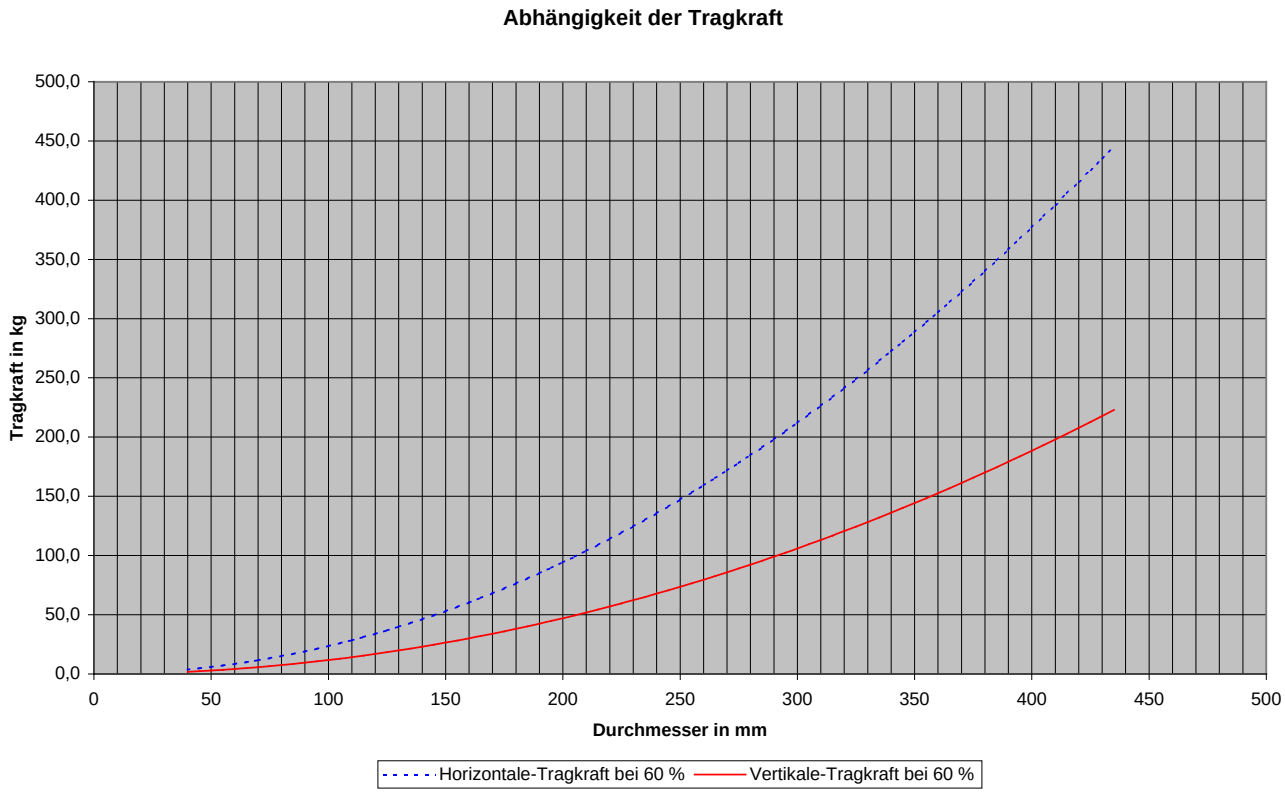
How high is the carrying capacity of the suction cup?

In the following diagram you can read the carrying capacity according to the diameter, considering the following points.

- The load capacity according to calculations use a safety factor of 2 for the horizontal pull-off force as well as for the vertical slipping off force .
- The coefficient of sliding friction **μ** was assumed with 0.5. This is a normal value for flat surfaces as given for glass and sheet metals. Under certain conditions another value could be set for other materials.
- Use at a height of 100 meters..
- Achieved vacuum in the suction cup of -0.6 bar.



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Basic knowledge about vacuum lifting devices

The values for the arithmetical carrying capacity are stated in the following table.

Depending on the diameter resp. the given surface of the suction cup, the calculated load capacity is stated at various vacuum values. Other influencing factors have not been taken into consideration for the calculation of the carrying capacity.

Diameter mm	surface in cm²	Carrying capacity in kg					
		Horizontal			vertical		
		0.6	0,7	0,8	**0.6**	0,7	0,8
40	13	**3.8**	4.4	5.0	**1.9**	2,2	2.5
60	28	**8,5**	9.9	11,3	**4,2**	4.9	5.7
80	50	**15,1**	17,6	20,1	**7,5**	8,8	10.1
100	79	**23.6**	27.5	31.4	**11,8**	13.7	15.7
120	113	**33.9**	39.6	45.2	**17.0**	19.8	22.6
140	154	**46.2**	53.9	61.6	**23,1**	26.9	30.8
160	201	**60.3**	70.4	80.4	**30.2**	35.2	40.2
180	254	**76.3**	89,1	101,8	**38,2**	44.5	50,9
200	314	**94.2**	110,0	125.7	**47,1**	55,0	62,8
220	380	**114.0**	133.0	152.1	**57.0**	66.5	76.0
240	452	**135.7**	158.3	181.0	**67.9**	79.2	90.5
260	531	**159.3**	185.8	212,4	**79.6**	92.9	106.2
280	616	**184.7**	215.5	246,3	**92.4**	107.8	123.2
300	707	**212.1**	247.4	282,7	**106.0**	123,7	141,4
320	804	**241,3**	281,5	321.7	**120.6**	140,7	160.8
340	908	**272,4**	317,8	363.2	**136.2**	158.9	181.6
360	1018	**305.4**	356,3	407.2	**152.7**	178.1	203.6
380	1134	**340.2**	396.9	453.6	**170.1**	198.5	226,8
400	1257	**377.0**	439,8	502.7	**188.5**	219.9	251,3
420	1385	**415.6**	484.9	554.2	**207.8**	242.5	277,1

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What requirements does EU standard EN 13155 impose on vacuum lifters?

5.2.2.1
At the end of the working area / at the start of the danger area, the vacuum lifter must still have at least double that carrying capacity. For this, the maximum working angle must be set higher than provided for.

5.2.2.2
Vacuum lifter without self-suction must have a pressure measurement unit that designates the work area and danger area.

5.2.2.4
The pressure measurement unit must be visible from the normal working position of the operator or crane driver.

5.2.2.5
Items of equipment must be in place to prevent losses of vacuum:
a) in the case of vacuum lifters with a vacuum pump: a vacuum tank with non-return valve, between tank and pump

5.2.2.6
A visual or acoustic warning system must be in place that warns of any loss of vacuum when the danger area is reached. This warning system must also function in the event of a power failure. This warning system is not the equivalent of the pressure measurement unit.

5.2.2.7
In the event of a power failure, the vacuum lifter must be able to hold the load for 5 minutes unless the vacuum lifter is being used in a cordoned off area to which people do not have any access.

5.2.2.8
Vacuum lifters used in special danger areas (such as on construction sites or in confined spaces) must be equipped with a second positive-connection retaining fixture or a second vacuum system. Each set of suction pads shall fulfil the requirement of the clause 5.2.2.1.

5.2.2.9
The releasing of the load shall be actuated by a two action control.

5.2.2.10
Control units for tilting or rotational movements must not be built with a non-locking button or similar fixture. (no self-holding)

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Which standard still applies to the handling of glass?

EU standard EN 13035 Teil 1 deals with an item of equipment for the storage, handling and transport of glass inside the plant.

EU standard EN 13035 Part 2 deals with an item of equipment for the storage, handling and transport of glass outside the plant.

This EU standard extends the scope of EN 13155 to all items of vacuum lifting equipment so all devices must now comply with these requirements, rather than only loose items of lifting gear.

What is the difference between 1-circuit, 2-circuit and 4-circuit vacuum lifting devices?

As the phrase indicates, a 1-circuit vacuum lifter only has one vacuum circuit. If this vacuum circuit leaks, the load falls to the ground.

A 2 circuit vacuum lifter has two vacuum circuits. If one vacuum circuit is leaking, the second vacuum circuit is still able to hold the load.
If the device is equipped in accordance with EU standard EN 13155 for operation on a building site, both vacuum circuits on a 2-circuit device must be able to carry double its load rating.
If one vacuum circuit should fail, half of the suction cups then fail too. A 2 circuit vacuum lifter always needs twice as many suction cups as a 1-circuit vacuum lifter.

There are four vacuum circuits on a 4-circuit vacuum lifter. If one vacuum circuit leaks, there are another three vacuum circuits that can hold the load.
If the device is equipped in accordance with EU standard EN 13155 for operation on a building site, the three remaining vacuum circuits must be able to carry double its load rating.If one vacuum circuit fails, 1/4 of the suction cups also fail. Usually, a 4-circuit vacuum lifter needs fewer suction cups than a 2-circuit vacuum lifter.

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Where can you find further information?

We are pleased to communicate our knowledge on our Facebook page, 'Pannkoke vacuum lifters'. If you have a Facebook account, simply click 'Like' on the page and we will keep you up to date. Otherwise, you can choose 'Just keep looking in occasionally'. Here is the link to the Facebook page:

www.facebook.com/Pannkoke.Vakuumheber

Another way to stay informed is with our YouTube channel 'Pannkoke vacuum lifters'. If you subscribe to this channel, you will be notified whenever there is something new to view. Here is the link to it.

https://www.youtube.com/channel/UC0sHy1FjrnE9VcixKaGPO1Q

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