Introduction

Vacuum cups grip a workpiece by evacuating air from the space inside the cup, creating a partial vacuum at a pressure below ambient. In simple terms one can size a vacuum cup based on the load, available vacuum and cup area. But engineers should consider several other factors when sizing vacuum cups for a given job.

http://www.pneumatictips.com/4475/2016/03/blog/size-vacuum-cup/

Theoretical Holding Force

Theoretical suction force is the cup force acting perpendicular to the workpiece surface. Theoretical holding force Ft is simply

$Ft = \Delta P \times A$

where ΔP is the difference between ambient and system pressure, and A is the effective area of the suction cup under vacuum. Theoretical holding force of a cup increases with the difference between ambient pressure and cup interior pressure, and with cup footprint.

Actual Ambient Pressure

Most catalog data on vacuum cups assume ambient air pressure is about 1 bar (actually 1,013.25 mbar). And vacuum-system manufacturers generally recommend vacuum levels of –0.6 to –0.8 bar for handling air-tight surfaces such as clean metal and plastic sheets; and vacuum levels of –0.2 to –0.4 bar for porous materials like cardboard boxes or particle board.

Also keep in mind that ambient pressure depends on elevation. Air pressure tends to drop by about 12.5 mbar per 100 m increase in elevation, which can reduce the attainable ΔP and maximum holding force. Thus, more or larger cups may be needed to compensate for lower ambient pressure.

Coefficient of Friction

How well a given suction cup grips and seals against a workpiece surface is another consideration. Friction coefficient μ approximates the relationship between friction force and normal force. Engineers need to take it into consideration when sizing vacuum cups. Typical estimated values for μ from several manufacturers are:

- Oily surface = 0.1
- Moist or wet surface = 0.2 to 0.4
- Glass, stone and dry plastic = 0.5
- Rough surfaces = 0.6

Note that these are just estimates. Engineers should test samples under actual operating conditions to get a better handle on μ. That's because a given workpiece surface can be smooth, rough, wet, dry or oily; and suction cups vary by material, hardness, lip contact shape and so on. All these parameters will influence actual friction properties.

Vacuum Diagram

Safety Factor

Never neglect a factor of safety. One can calculate theoretical holding forces, but many external influences affect actual performance. Even in mundane applications, calculations should include a safety factor of at least 1.5. Many vacuum-system manufacturers recommend a safety factor of at least 2.0. In high-speed swinging or swiveling operations, a safety of 2.5 or higher might be needed to ensure a tight grip on work pieces and safety of nearby workers.

Load, Orientation and Acceleration Forces

One can calculate the required diameter and effective gripping area of a vacuum cup. But it's usually preferred to determine the necessary holding force. From there, users can choose from a range of cups that meet the requirements based on size, shape, material, cost and manufacturer.

First, determine the workpiece mass, m, by multiplying volume by material density. Then determine holding force based on these common configurations. For more complex motions or orientations, discuss the design with a manufacturer's application engineer, or rely on sizing software available from several vacuum-system suppliers.

For a horizontal vacuum cup with a vertical lifting force:

$F = m \times (g + a) \times S$

where F = holding force, N; m = mass, kg; g = acceleration of gravity, 9.81 m/sec2; a = system acceleration, m/sec2; and S = safety factor.

For a horizontal vacuum cup moving a load in a horizontal direction:

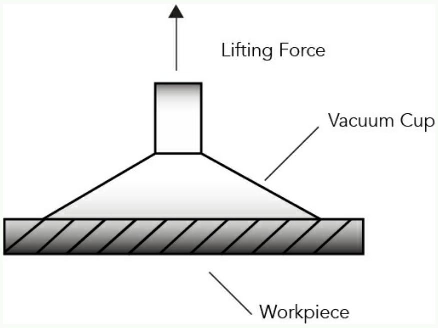
$F = m \times (g + a/\mu) \times S$

For a vertical vacuum cup moving a load in a vertical direction:

$F = (m/\mu) \times (g + a) \times S$.

Typically, in such an orientation, the safety factor should be 2.0 or greater.

After calculating holding force, one can find appropriate data for “pull off” or “breakaway” force of different cups from catalogs or manufacturers' websites. (Note that catalog specs are typically listed for a specific vacuum, say –0.7 bar.) The listed breakaway force should exceed the calculated holding force. Depending on the application a single cup might suffice, or the total holding force may be distributed among several cups.


Lifting Force
Vacuum Cup
Workpiece