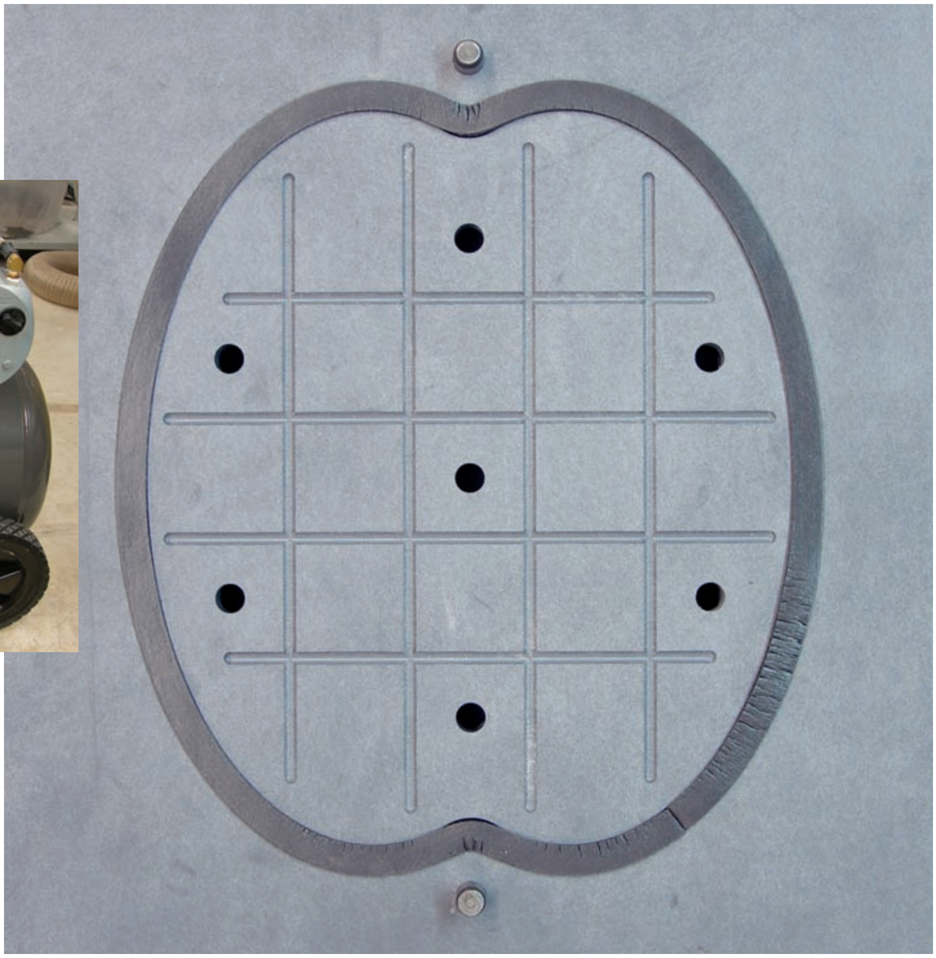
Getting a **Grip** Under **Vacuum**

by Todd M. Reith

Photos by Author

Identifying a method to hold down your workpiece is usually the first obstacle that you need to overcome with a new project. Of course you have the stand-by vise and clamps, but what if the piece that you are trying to hold down is awkward in shape, deforms under clamping pressure, or is non-ferrous? Or, what if you just want a fast, repeatable method of holding your pieces down? Why not use what is already around us? That's right, the air! The atmosphere at sea level exerts 14.7 pounds per square inch.[1] In areas above sea level, the holding force is less, but still significant. Creating a vacuum under a workpiece is a method of using that downward pressure to our advantage.

1



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Although using a vacuum as a method of workholding may not be as secure as a vise, magnetic chuck, or clamps, it can be used effectively to hold any material in nearly any size or shape. The advantages of vacuum clamping include the following: clamping of thin parts or parts that deform under traditional clamping, hold-down of non-magnetic parts, reduction of setup and clamping time, the ability to machine profiles and pockets without the interference of clamps or a vise, and a more flexible system that can be adapted quickly for different materials and machining applications. The only drawback of using a vacuum is that smaller parts are more difficult to hold down.[2]

To understand the effectiveness of using a vacuum, we need to understand the effects of vacuums at different elevations and the additional forces encountered during machining operations.

Atmospheric pressure is the downward pressure by the air above and around us being pulled to the Earth by gravity. A barometer is used to measure this air pressure in linear inches of mercury within a glass tube. At sea level and in perfect conditions, the barometer measures 29.92 inches of mercury (in-Hg).[1] By removing this air under our workpiece, we create a vacuum, and the air above acts as a downward force.

Table 1 shows barometric readings at different elevations. By knowing the barometric pressure in your area, the effectiveness of your vacuum pump, and the surface area of your part under vacuum, you can calculate the hold-down force.

Altitude (feet)	Barometer (in-Hg)	% of Change of Barometric Pressure	Downward Pressure per Square Inch (psi)	Effective Vacuum Pump rated 25 in-Hg 83.5% Efficient (in-Hg)	Effective PSI Pump rated 25 in-Hg 83.5% Efficient (psi)
0	29.92	0.00%	14.70	24.98	12.64
2000	27.82	-7.00%	13.70	23.23	11.44
4000	25.84	-13.00%	12.79	21.58	10.68
5000	24.90	-16.80%	12.23	20.79	10.21
10000	20.58	-31.20%	10.11	17.18	8.44

Table 1. Atmospheric and pump efficiency effects on downward forces.[1,3]

For example, if the part that you are machining is 3.50" x 3.50", and you are at sea level with a pump that is rated at 25 in-Hg, your maximum hold-down force under vacuum would be 150.5 pounds. [(3.50" x 3.50") square inches x (25.00 in-Hg/29.92 in-Hg) x 14.70 psi].

In addition to knowing the amount of downward pressure on your part under vacuum, we need to be aware of additional forces encountered during the machining process. Factors that will twist or lift the part off the fixture include side rotational forces from the edges of the cutter, upward forces influenced by the aggressiveness of the depth of cut, and other machining forces. All of these forces can be addressed by choosing the correct type of vacuum pump, tooling, and fixture design, maintaining a good seal, and maximizing the part surface area under vacuum.

Choosing the correct type of vacuum pump involves understanding the physical properties of the material that you are trying to hold down and the type of fixture you select. Porous materials will draw the air completely through the workpiece and you will loose your vacuum. For these types of materials it is best to use a blower type pump with the ability to recover large volumes of air. The amount of air a pump can pull, or its flow rate, is measured in cubic feet per minute (cfm). Typical blowers can draw as much as 27 cfm to 1350 cfm of air.[4] A rotary vane style pump works well for most applications where the material is dense and there is minimal porosity. Rotary vane style pumps are usually more quiet and efficient, but only draw <1 cfm to 112 cfm, having a low recovery rate.[5]

Rotary vane and blower type pumps are power rated on average between 20 to 25 in-Hg. Some pumps can draw as much as 29.5 in-Hg.[4, 5] Due to the internal leakage within the pump, it is impossible to maintain an absolute vacuum. To improve the performance of the pump, the use of a vacuum storage tank can be added to the system. The addition of a storage tank will decrease the amount of time to remove the air within the fixture and provide additional volume of vacuum quickly if a seal is momentarily lost. A typical vacuum system would include a vacuum rated tank, vacuum pump, vacuum pressure switch with high & low settings, in-line filtration, exhaust filter/muffler, and a flexible vacuum rated hose with fixture connection fittings (Photo 1).

The geometry of the tooling that you use can also greatly effect how well your parts stay in place. Traditional end mills have an upward flute design to eject the chips and will pull the material upward. If the depth of cut and/or the rake angle of the cutting edge is too aggressive, the cutter may pull the piece completely off the fixture. If applicable, the use of down-shear end mills will help push the material downward into the fixture.

Vacuum fixtures are classified as either dedicated for a specific part or universal grid-style that can be easily configured for many different parts. Both types should have unrestricted air flow, and be designed to allow the vacuum to be drawn without resistance. In addition, a surface with high friction properties is desirable to help prevent parts from twisting or moving out of place. The use of locating pins not only aids with quick part positioning, but also helps keep workpieces in place (Photo 2).

Lower Stability	**Higher Stability**	
Universal	**Fixture**	**Dedicated**
Heavy	Machining Aggressiveness	Light
High	Air Seal Loss	Low
Low	Pump Flow (cfm)	High
Low	Pump Power (in-Hg)	High
Low	Barometric Pressure	High
Small	Part Size (Surface Area)	Large

Table 2. Vacuum stability trends

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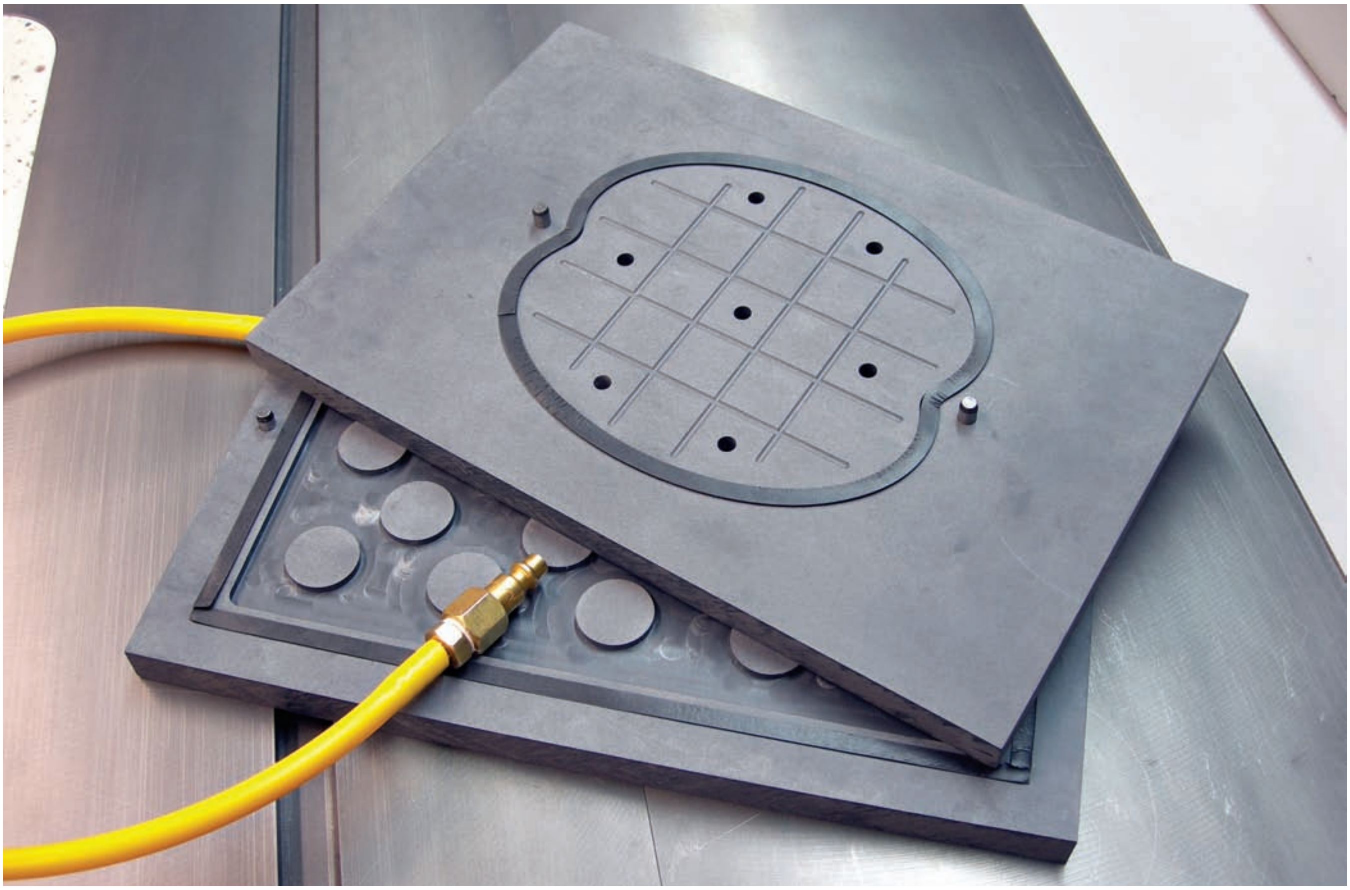

Dedicated fixtures are custom machined solely for the workholding of a single part. The advantages of a dedicated fixture include increased surface area of the part under vacuum, reduction of air loss, and machining through the material without losing vacuum. Disadvantages include the high initial cost of creating the fixture, additional setup time, and the single purpose non-flexible nature of the fixture.

Small or narrow parts, or parts with through pocketing are ideal candidates for a dedicated fixture. By creating an off-set curve within the perimeter of the part, you can maximize the surface area under vacuum. In-board gasketing ensures a tight air seal by use of a foam rubber gasket placed within a channel, within the perimeter of the part. All-Star Adhesives (Warren, RI) and Vac-U-Lok (Rockford, IL) sell a complete line of gasketing materials in different densities, thicknesses, and widths. These products are designed specifically for vacuum fixturing and fit within an easily machined slot. Under compression, the gasket material creates an air-tight seal.

Workpieces that require contour profiling and interior pocketing are also best held in place with a dedicated fixture. The fixture can be machined to accommodate the profiling depth of cut below the Z-axis of the workpiece, where normally you would leave a few thousandths of material to avoid cutting into the work table. With the ability to machine through the material, you eliminate the labor intensive break-out process, excessive deburring, and pre-finish clean-up.

Parts that are awkward in shape and cannot be held flat can be held under vacuum by using a dedicated, CNC-milled, three-dimensional form or a form casting. Edward Hoffman of the New Jersey Institute of Technology describes a method of creating an epoxy casting around the workpiece to create a form fixture.[6] Initially a form is placed around the workpiece and epoxy is pored into the form. Once the epoxy has cured, the workpiece is removed and the inside surfaces of the casting are machined to accept a gasket seal and a series of passages to permit a vacuum to be drawn. The odd-shaped part can now be held securely in place where traditional methods would be difficult.

Universal or grid style vacuum fixtures are more flexible and can be dynamically configured for most workpieces. Vacuum grid chucks are traditionally made from a flat piece of stock with a series of equal distance grooves in a grid pattern. To hold a part in place you either fill the grooves with a gasket to a shape undersized to the part, or you use a mask that matches the slightly undersized shape of the part. Edward Hoffman also suggests the use of the Dunham vacuum chuck.[6] Instead of a series of grooves, the Dunham chuck uses a series of holes in a grid. Each individual hole has a threaded valve that can be independently controlled to open and close air-flow. The part can be placed directly on top of the chuck or can be used in conjunction with a mask. Advantages of using a universal fixture include a low one-time cost, high flexibility multi-use purpose, and reduced machine setup time. The drawbacks are the reduced surface area under vacuum, increased loss of vacuum, and the inability to hold odd-shaped workpieces.

To help with the understanding of the forces that aid or inhibit a strong vacuum, table 2 is provided, showing factors that contribute to low and high stability conditions. Understanding the forces around you, adapting your machining techniques, and choosing the right fixture for your application will help make working under a vacuum a viable workholding solution.

References

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Other Resources

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