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HEAVY LIFTING: MARK SFIRRI WEIGHS IN AT PENN STATE GALLERY

AUBURN OAKS MEMORIALIZED IN MOULTHROP BOWLS

TERRY MARTIN'S *THE CREATIVE WOODTURNER* REVIEWED

HOW TO GET THE MOST FROM YOUR VACUUM CHUCKING SYSTEM

John I. Giem

The author uses an orifice plate mounted on a vacuum chuck to measure the airflow rate into the system. This test entails systematically opening orifices on the plate, taking readings on a vacuum gauge, calculating airflow, and graphing the data.

After I published my first article on vacuum chucking systems (*AW*, Vol 26, no 1), I learned that many turners still had questions: How well is my system actually working? What size vacuum pump do I need? Can I use an old pump? Why can't I get enough suction (vacuum) to mount my bowls? I began investigating these issues for my own benefit as well as for others. Underlying my research is the sobering fact that if you do not monitor the vacuum within your system, your vacuum levels, and therefore holding power, are unknown. And without knowing how securely your workpiece is held on the lathe, you are at greater risk of ejecting the workpiece and injuring yourself or others.

Vacuum basics

A vacuum chuck uses air pressure to hold a piece of wood on the lathe. A vacuum pump removes air from within the vacuum chuck, so the air pressure outside is greater than the air pressure inside, pushing the workpiece onto the chuck. The air moves from the chuck through the lathe spindle and down to the pump via filters, valves, and tubing. All of this hardware constitutes the vacuum system, which has three distinct regions: the pump, the plumbing, and the workpiece.

To achieve the desired vacuum at the chuck, the pump must remove all the air leaking into the system through the workpiece, from the seal between the workpiece and the chuck, and from within the plumbing. The vacuum generated at the pump depends upon the amount of air it pumps out of the system. With nothing connected to the input or output, the pump will move the most air and there will be no vacuum. If we starve or limit the air going into the pump, the vacuum gets stronger (*Figure 1*). Like barometric pressure, vacuum is commonly measured in units of mercury—inHg or cmHg; 1 inHg equals 2.5cmHg. The higher the number, the stronger the vacuum.

It is safe to assume the workpiece will leak air into the system because most woods are porous. This leakage is often difficult or impossible to reduce. The seal between the chuck and the workpiece may also leak. Leakage in the system plumbing is easier to find and eliminate. Likewise, restrictions to the airflow will cause changes in the vacuum levels, and those restrictions can also be identified and reduced.

The strongest vacuum will be at the input of the pump and the weakest, within the chuck. Since the vacuum generated by the pump gets stronger by decreasing airflow, the best vacuum at the chuck will occur when leakage into the system is minimized. This means any air leaking into the system plumbing will degrade the vacuum at the chuck, depending on where the leak is and how much air flows in. The system leakage can cause additional vacuum losses due to airflow restrictions between the chuck and the pump.

A simple exercise with a drinking straw and cup of water will illustrate these principles. Put your finger over one end of a straw and suck on the other end. This represents a good vacuum system with no leakage. Your mouth is the pump, the straw is the plumbing, and your finger is the workpiece. The entire vacuum that your mouth generates is delivered to your finger. Now remove your finger, put the straw in the water, and suck. The water flowing through the straw represents leakage at the workpiece. If you pinch the straw, you will reduce the flow of water, having introduced a restriction in the plumbing. The same holds true for the plumbing of your vacuum system. Make a small hole near the middle of the straw and try to suck up water. The hole in the straw represents leakage in the system's plumbing, degrading your ability to draw water. Logically, the larger the hole, the greater the degradation. Pinch the straw again, above and then below the hole, and the flow of water will be reduced or stopped altogether.

The straw exercise illustrates that system performance will always be less than or equal to the pump's performance alone. The overall performance of a vacuum chucking system depends upon three things:

- Identifying and reducing the sources of air leaking into the system.
- Reducing restrictions to airflow so that air can move to the vacuum pump and out of the system efficiently.
- Assessing the vacuum pump's performance, checking for internal leakage from wear, and how its air-moving ability matches up with any leakage from the system or workpiece.

Testing your system

A series of five tests will allow you to check and improve the three areas of concern noted above. It is best to run the tests in the order shown on these pages. The first three are simple and easy. The last two are more involved and possibly unnecessary for your system, depending upon the results of the first three.

The basic tests

1. Leakage drop-off test. If you seal off the system and isolate it from the pump, you can detect leaks through the readings on the vacuum gauge. To conduct what I call the leakage drop-off test, turn on the pump, place a nonporous flat plate over the vacuum chuck, and run the system to its maximum vacuum. Then isolate the pump from the rest of the system using an isolation valve or clamp *(Photo 1)*. Watch the vacuum gauge to see how fast the vacuum drops; the slower it does, the less leakage in the system. A good system should hold the plate on the vacuum chuck for four minutes or more. Every time I use my system, I perform this test to be sure all is well before I start turning. I can judge the leakage performance by watching the vacuum gauge; I do not need to wait for the plate to drop off.

2. Open chuck test. This test helps find restrictions in the system between the manifold, where the gauge is located, and the vacuum chuck. I discovered the need for this test when one day I noticed the vacuum pump was running, but the vacuum at the manifold was not zero, even though I had nothing mounted on the vacuum chuck.

With the vacuum system fully assembled and ready to use, but with the pump off, record the vacuum gauge reading at the manifold. It should be close to zero. Now, with the manifold bleed valve closed and without placing anything on the chuck, turn on the vacuum pump and read the vacuum gauge at the manifold. You should see a small increase in the reading caused by the airflow ▶

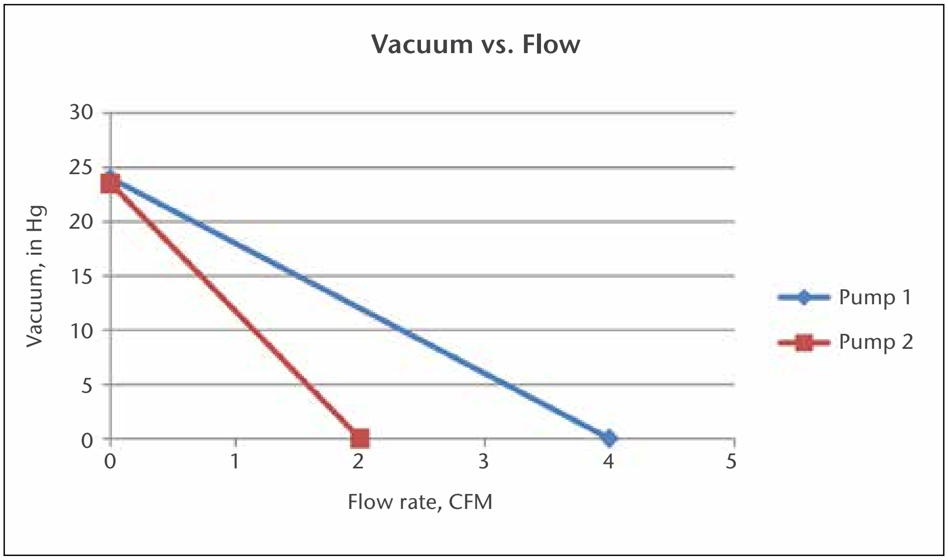

Figure 1. This graph shows the performance of two ideal pumps of different capacities: 4 cfm for pump 1, 2 cfm for pump 2. Each reaches the zero vacuum level at its maximum air-moving capacity.

The aluminum block is the system's manifold, the point where the components come together. At the top is a bleeder valve, used to set vacuum levels. At the bottom is the connector and hose leading to the fittings on the lathe. On the left is the isolation valve, connected to the hose leading to the filter and vacuum pump, and at the upper left is the manifold vacuum gauge.

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A rotary vacuum adaptor ties the rest of the system into the lathe. Three manufacturers make these adaptors for the same lathe. Notice the differing methods implemented to achieve similar functionality. The adaptors are oriented to show the critical orifice, or narrowest opening, for each. The unit on the left will have an airflow estimated at about 30% of the unit on the right.

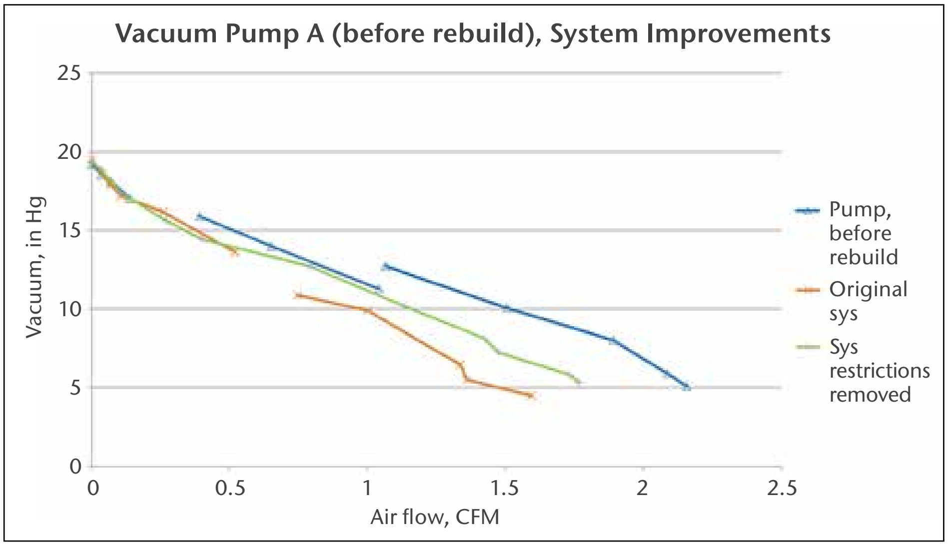

Figure 2. This graph shows the effects of improvements in the system. Before being rebuilt, the pump's maximum vacuum was 19.1 inHg. When placed in a system, the system performance dropped by nearly half, as represented by the bottom orange line. After a few improvements, performance (center green line) moved upward. The system's performance curves follow that of the pump until the air flowing through the restrictions start to limit the achievable airflow. Reducing those restrictions can be significant. In this case a mounted object with approximately 1.5 cfm leakage would be held at 5 inHg (rather marginal). With the improved system, that same item would be held at about 7 inHg, which is enough of a difference to impact whether some workpieces can be mounted at the lathe.

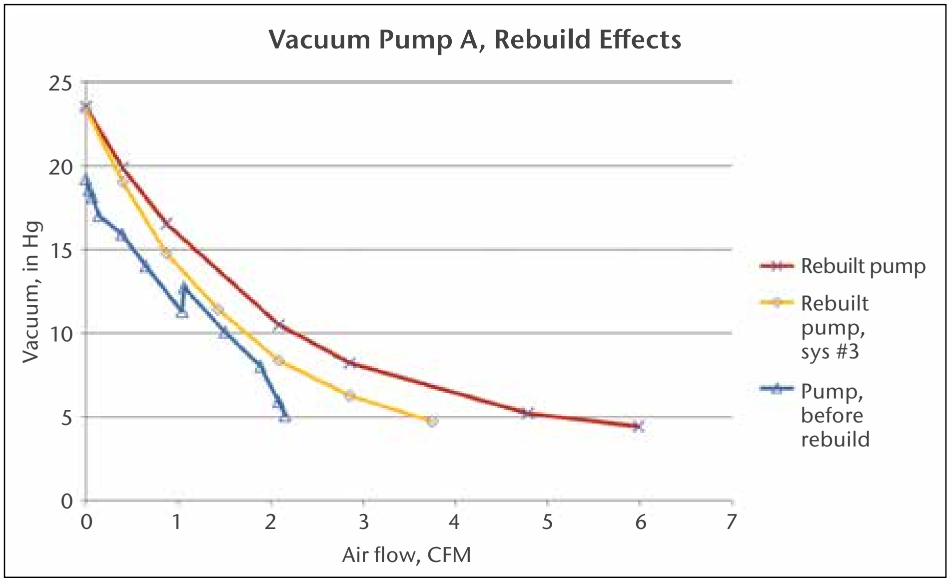

Figure 3. The effects of rebuilding the vacuum pump used for Figure 2. Before rebuild, the maximum achievable vacuum was 19.1 inHg. After rebuild, that rose to 23.5 inHg. The rebuilt pump also shows improvement in the airflow rates for a given vacuum because of the reduced leakage around the pistons of the pump. Leakage within the system will produce a degradation of performance similar to that of a badly worn pump.

restrictions between the manifold and the vacuum chuck. The airflow path will include the spindle bore, the rotary vacuum adapter, hoses, hose barbs, and any other fittings.

When you check the path of air through the plumbing, look for the critical orifice first. This is the place in the airflow path with the smallest area in cross section. It can be caused by any narrowing of the airway at the plumbing fittings, including a kink in the hose or the passage through an adapter. The critical orifice will dominate the restrictions to the airflow for the entire system. To that end, it is easy to check the size of the bore through the rotary vacuum adapter—the larger the better *(Photo 2)*.

This test illustrates that the vacuum reading at the chuck will be lower than that at the manifold. After all, in this test the vacuum at the chuck is zero and the vacuum at the manifold is not zero. What is a reasonable vacuum reading? In one of the systems I tested, the initial vacuum was 6 inHg (15cmHg). I then made several modifications: removing unnecessary parts; changing to a shorter, larger diameter hose; and installing larger hose barbs. On retesting, the vacuum at the manifold dropped from 6 inHg to 2 inHg (5cmHg), indicating airflow had improved markedly.

If there are significant restrictions between the manifold and the pump, this may affect the open chuck test by limiting airflow, thus masking any other restrictions. If you have a second vacuum gauge, measure the vacuum at the pump while running the open chuck test. If the reading at the pump is significantly greater than at the manifold, you may have another critical orifice between the manifold and the pump. Check the entire system, looking for places where airflow may be restricted. Ensure the air filter between the manifold and pump has not been clogged with dust, for example.

Using larger diameter hose will provide better performance, improving incrementally with each step up in size. A 1" (25mm) hose would be better than ⅜" (10mm), although the benefits of upgrading to that size may not be worth the extra effort and inconvenience.

If your vacuum pump is at a distance from the lathe, the length of plumbing may cause degradation. Larger plumbing from the pump to the lathe may be justified by offsetting the losses due to the plumbing length. However, it may be better to move the pump closer to the lathe rather than increase the size of the plumbing. Making multiple vacuum readings simultaneously at different places between the pump and lathe while running the open chuck test will help identify significant losses.

3. Pump blocked-input test. Not all pumps are created equal. For an ideal vacuum pump, a graph of the manufacturer's specifications would be a straight line from the maximum vacuum with no airflow to the maximum flow with no vacuum (*Figure 1*). But in the real world, actual performance does not always follow a straight line because of the effects of internal leakage and airflow restrictions within the pump itself. The vacuum generated depends on the amount of air the pump moves. Therefore, measuring the vacuum generated with the pump's input blocked is a good way to gauge excess pump wear.

The test itself is easy: Connect a vacuum gauge directly to the pump's input port. Turn the pump on and read the vacuum level. To interpret the readings correctly, you need to determine the target vacuum level you expect, making allowances for altitude.

For example, a good pump will deliver a vacuum within 1 to 2 inHg (2.54 to 5.1cmHg) of the local air pressure. At sea level, where the average air pressure is 29.5 inHg (75cmHg), the pump would deliver around 28.5 to 27.5 inHg (72.4 to 69.9cmHg). As the altitude rises, the average air pressure drops about 1 inHg for every 1,000 feet. I live in northern Colorado, 5,000 feet above sea level, so my average air pressure is 24.5 inHg (62.2cmHg), or 5 inHg (12.7cmHg) lower than at sea level. Accordingly, that same pump's expected vacuum would be 23 to 24 inHg (58.4 to 61cmHg).

I have acquired and borrowed many different types of vacuum pumps—some new, some used, and some badly in need of refurbishing. Most pumps achieved about the same vacuum level in a blocked-input test. Internal leakage due to wear accounted for the differences. As an example, I tested two used piston pumps before and after they were rebuilt. For one, the maximum vacuum before rebuild was 19.1 inHg (48cmHg); it rose to 23.5 inHg (60cmHg) at 5,000 feet after being rebuilt. There was also a significant improvement in the measured flow rates (*Figures 2, 3*).

The more-involved tests

The last two tests entail recording and graphing multiple readings of airflow as you deliberately control and gradually increase the amount of leakage at the chuck, using a tool called an orifice plate (*see sidebar*). When these tests are done, the measurements will provide a reasonable picture of the pump and system flow rates, which you can then use to determine how well your system is functioning and whether you want to refine it.

An orifice is a small hole of known size drilled through a plug or plate. By knowing the pressure drop across the orifice and its size, I can determine the air flowing through it. The orifice plate I devised is similar to the plate used in the leakage drop-off test, but with numerous small holes drilled in it. The plate lets me make consistent airflow measurements. By always using the same vacuum gauge and set of orifices for my measurements, I get consistent data, which tells me that changes in the measurements are due to system changes and not the measuring tools.

When running airflow tests, use a large vacuum gauge like the one pictured left. The smaller one is an inexpensive unit commonly used in vacuum systems and may not deliver sufficient accuracy and readability. Also, inexpensive gauges may not be accurately calibrated, leading to differences in the readings when using more than one gauge. For consistent measurements, gently tap the gauge before each reading to help overcome internal friction of the needle mechanism.

To minimize errors, make a separate port on the side of the vacuum chuck and take the vacuum measurements there. Otherwise, leakage or restrictions somewhere in the system may compromise the data.

Begin with all orifices masked off and verify the leakage for the equipment being tested is low enough that it will not significantly affect the readings. (I used one or two layers of black plastic electrical tape to mask off the holes.) Unmasking an orifice admits air, so the resulting vacuum will drop. The amount of change depends upon the number and size of the orifices. The ability to see or measure the change depends upon the sensitivity of the vacuum gauge used. In these measurements, I used a 4½"- (114mm-) diameter vacuum gauge with graduations for every ½ inHg (*Photo 3*).

Uncovering more orifices of the same size or switching to a larger orifice will increase the airflow. The number of ▸

uncovered holes along with the measured vacuum allows the determination of the flow rate. Begin by uncovering one hole and working upward. Take five or more vacuum readings using different sets of the same-size holes. Do the same for the sets of larger holes.

For multiple readings at each data point, move the tape between readings but do not change the number of open orifices, just the positions. Averaging the set of readings helps reduce errors caused by differences within the set of orifices. Do not use orifices of different sizes at the same time, as that will introduce too many variables. When graphing the data, each set of measurements with a single-sized orifice will generate a single line or curve. Each set of orifices of the same size will have a different offset in its curve and usually will not line up with the adjacent-sized orifices due to using uncalibrated equipment. To convert the vacuum readings for different-sized orifices, I utilized tables listing the flow rates for various orifices, given the vacuum across the orifice (*Tables 1, 2*).

In order to make the analysis easier, I used curve-fitting techniques to model the data in the charts and developed a set of equations. They made the analysis faster and reduced errors encountered when interpolating between the data points in the table.

Orifice Characteristics

	Orifice Flow, CFM			
Vacuum level, in. Hg	#74	1/32"	1/16"	1/8"
0	0	0	0	0
1	0.0137	0.0318	0.2047	0.8125
2	0.019592	0.053842	0.293977	1.17058
4	0.025484	0.075884	0.383255	1.52866
6	0.02893	0.088778	0.435479	1.738123
8	0.031375	0.097926	0.472532	1.88674
10	0.0349	0.13	0.501237	2.002015
12	0.0349	0.13	0.524756	2.1
14	0.0349	0.13	0.53	2.1
16	0.0349	0.13	0.53	2.1
18	0.0349	0.13	0.53	2.1
20	0.0349	0.13	0.53	2.1
22	0.0349	0.13	0.53	2.1
24	0.0349	0.13	0.53	2.1

Table 1. This is a simplified version of a downloadable chart showing the flow rates for various-sized orifices as a function of the vacuum across them. The flow rates reach a limiting value at higher vacuum levels due to turbulent air flow as it reaches supersonic levels. Consequently, at the higher vacuum levels the flow does not increase with increasing vacuum.

Orifice	Eq.	Range. 0 to in Hg	Const.
1/32	F=0.0318*ln(vac) + 0.0318	10	0.13
1/16	F=.1288*ln(vac) + .2047	13	0.53
1/8	F=0.5116*ln(vac) + 0.8125	11	2.1
3/16	F=1.1517*ln(vac) + 1.8618	13	4.8
1/4	F=2.0279*ln(vac) + 3.2277	13	8.5
#74	F=.0085*ln(vac) + 0.0137	10	0.0349

Table 2. To make the calculations easier and minimize errors in making interpolations from the tables, I derived these equations from data tables. They are used to calculate the flow rates for a given vacuum. The first column is the orifice size. The second calculates the flow for lower vacuum levels, the third is the vacuum level where the flow reaches supersonic speeds and becomes constant, and the fourth is the flow rate in cfm for vacuums larger than given in column three.

Calculate the vacuum averages for each set of readings and then determine the flow rates using the derived equations. Plot these data pairs on a graph. Recognize that when you change to different-sized orifices, there will be a discontinuity between the plots because you are using uncalibrated equipment. However, the discontinuities will not change the interpretation of the graphs or the need for any corrective actions.

Generally, I do not make flow measurements below 5 inHg (13cmHG) due to vacuum gauge inaccuracies, and I will not knowingly use vacuum chucks for turning below that level due to the risk of dislodging the workpiece.

4. Pump flow test. Using the flow measurement procedure above, measure the pump performance and plot it on a graph with the vacuum on the vertical axis and the flow rate on the horizontal axis. For this test, connect the pump and the vacuum chuck with a short length of large-diameter hose and suitable fittings to avoid or minimize airflow restrictions (*Photo 4*). The vacuum gauge should be connected to the side of the chuck, using a separate port from the one being used by the vacuum pump.

This test will reveal several items of interest. The pump's vacuum level at zero flow will correspond to the vacuum measured when doing the vacuum pump blocked-input test. From that point the pump performance curve will move downward to the right. If the curve is a reasonably straight line, the pump is performing well. If the plot starts out as a straight line and then curves downward, the pump may have some internal flow restrictions and/or leakage.

The intersection achieved by extrapolating the end of the curve down to the flow axis indicates the flow capacity of the pump. If you are not making altitude corrections for pressure and volume and are using uncalibrated equipment, be wary of comparing this projected performance with the pump's specifications.

5. System flow test. Once system leakage has been fixed, all of the system's resources will be available to remove leakage from the workpiece. To measure system performance, mount the vacuum chuck and orifice plate onto the lathe. Do not turn on the lathe, but fit the vacuum gauge into a port on the side of the chuck. Using the procedure outlined above, measure the flow performance for the complete system.

With all the measurements complete, plot the system performance on the same graph as the pump measurements. The system vacuum versus flow measurements will always be at or below the pump's curve, as anything between the pump and the chuck will restrict the flow with increasing flow rates (*Figure 4*). The system curve will follow the pump curve at the lower flow rates. As airflow increases, restrictions in the system will cause the vacuum levels to fall off faster; the greater the restrictions, the faster the fall-off. For example, at 5 inHg (13cmHg), the pump may be able to move four cubic feet of air per minute (cfm), but the system will only allow 2 or 3 cfm because of internal system airflow restrictions.

If the pump capacity is considerably greater than what the system will allow, the excess pump capacity is not usable. Many turners dismiss leaks as unimportant, believing their pump is large enough to negate the effect of leaks. But the ability to handle leakage is also dependent upon the system plumbing, not just the pump's capacity. If a small-capacity pump is used in place of a large one, the system may not be the limiting factor and system performance will closely follow the pump's performance.

The pump and system performance curves show how pump capacity and the system plumbing interact. A small capacity pump is the limiting factor in the ability to remove workpiece leakage. But as pump capacity increases, airflow restrictions start to take effect. For large leakage from workpieces, the system plumbing is the limiting factor, and in this case the full capacity of the pump may not be usable.

Another factor to consider is pump downtime—the elapsed time from turning on the pump until full vacuum is generated to hold the workpiece on the chuck. Larger pumps will improve pump downtime but may be limited by system airflow restrictions. For smaller or remotely located pumps, a vacuum reservoir can improve pump downtime. Use an isolation valve at the manifold and a reservoir connected to the plumbing on the pump side of the valve. Close off the isolation valve and let the pump evacuate the reservoir, reaching full vacuum. Place the workpiece on the vacuum chuck and open the isolation valve. The workpiece will be quickly grabbed by the chuck. In some instances, this was the only way I could get some workpieces mounted.

If you want to quantify any improvements you make to your system, measure both the pump performance and system performance and plot them on a graph. Any improvements you make will move the system performance closer to the pump's performance. This will also verify that any changes made did not have adverse effects.

Is the reduction of the vacuum at the chuck due to flow restrictions really significant? It can be, as Figure 3 illustrates.

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To assess a pump's airflow, use large tubing to connect it to the vacuum chuck. Fit the vacuum gauge in a separate port on the side of the chuck. With the pump running, uncover the desired number of orifices of the same diameter and record the vacuum level. Run repeated tests, each time uncovering the same number of same-sized orifices and covering the previous set. This photo shows three 1⁄32" orifices opened.

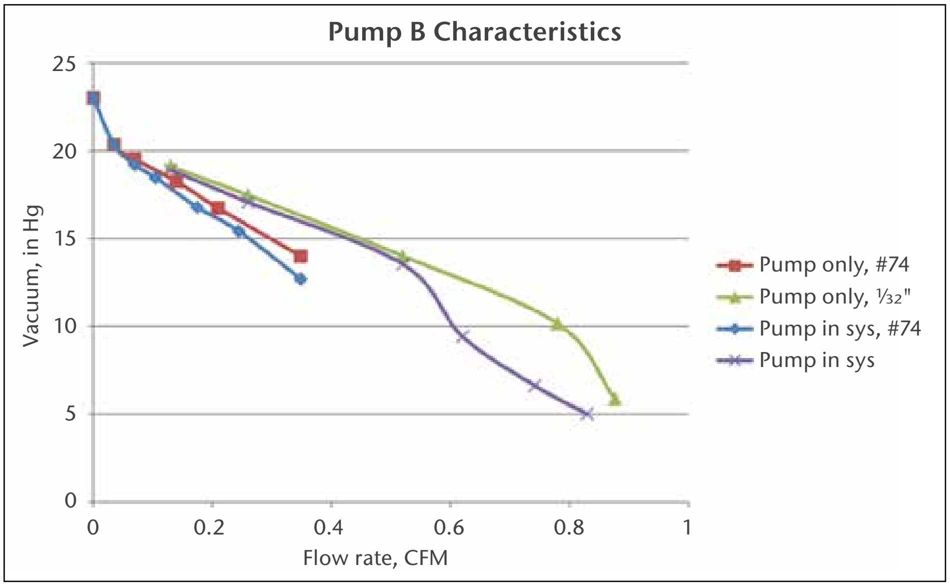

Figure 4. This graph illustrates the difference between the operation of the pump itself and the entire system. The testing used two sizes of orifices in the orifice plate; the discontinuity occurs where the plots switch from one size to the other. At low flow rates, the system and pump curves track each other closely. But at higher airflow rates, restrictions in the system cause system performance to drop faster than that of the pump.

In the case of a workpiece that yields 1.5 cfm leakage, the workpiece would not have been mountable with the original system, whereas the graph predicts that with the improved system, it would be held at 7 or 8 inHg (18 or 20cmHg). In this case, not having the improvements would have compromised the ability to mount the workpiece. After the pump was rebuilt, the vacuum holding power was further improved.

To further improve holding power, repair plumbing leakage as needed. Thread sealing tape can be used to seal where two parts are screwed together. Be sure there are no loose ends of tape projecting into the flow path. These protrusions can have an impact on the flow and could dislodge and go into the filter or pump. An alternative to thread tape is silicone sealant.

A system at its best

Understanding how your vacuum chucking system works and being able to test, improve, and maintain it will greatly improve your use of this versatile lathe accessory, while decreasing the risk of a lathe accident. And, even with the use of a vacuum system, always support the work with the tailstock whenever possible. ■

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How to make an orifice plate

To make your own orifice plate used in testing the effectiveness of your vacuum chucking system, you will need the following:

- An 8" square aluminum plate. The thickness is not critical as long as it is stiff enough not to warp and allow leakage. A softer aluminum alloy is easier to drill. You can substitute a different metal or plastic as long as it passes the leakage drop-off test before drilling the holes for the orifices.
- Drill bits in these sizes: 1/32", 1/16", and No. 74. Small, numbered bits are available through specialty retailers on the Internet. Get several of each size and expect to break a few. You may also need an adaptor to hold them in the drill.
- Colored marking pens and/or a sharp scribe for laying out the hole locations.
- Fine sandpaper and alcohol to prep and clean the plate.

Getting started

Lightly sand and clean both sides of the plate, giving it a smooth matte finish without deep scratches. Find the center of each face, mark, and center punch it. Mount the vacuum chuck you plan to test on the lathe, and then mount the plate onto the vacuum chuck. Use a point center in the tailstock to center the plate on the chuck, using the center punch marks for alignment.

Turn on your vacuum system to apply vacuum. With the lathe running at a slow speed, mark a series of circles on the plate. The outer circle should be at least 1" (25mm) larger in diameter than the chuck. The second circle should be about ½" (12mm) inside the chuck. Make the third circle ½" (12mm) inside the second, and the fourth ½" (12mm) inside the third (*Photo a*). Draw diagonal lines through the center, intersecting the circles and denoting the locations of the orifices. You do not have to locate the orifices precisely, as long as they are spaced far enough apart so they do not interact.

With the lathe off and the tailstock out of the way, place the toolrest close to the surface of the plate. Set the height so that a marker or scribe will pass through the center point. Using the indexing feature of the lathe, draw lines across the surface of the plate, with each line passing through the center and crossing over the three inner circles. My lathe has 24 index points, giving 15° between each of the diagonals. Where the diagonals intersect the three inner circles denotes the locations of the orifices. The innermost circle will have 1/16" holes, the middle circle 1/32" holes, and the outer circle No. 74 holes. If you used colored markers, each circle will be a unique color and will contain only one size of holes.

Although not necessary for making the measurements, I used the outer circle as a guide to cut the orifice plate into a circular disk. This allowed the use of a fixture to simplify drilling the holes in the desired pattern.

I strongly suggest using a drill press with an adapter to hold the small bits; you will have better control, less drill bit breakage, and the entry and exit points for the holes will be smoother. To avoid breaking the small bits, use very light pressure and, if using a handheld drill, keep the bit aligned. If you break a bit and cannot get it out, mask off that area with two or more layers of electrical tape on both sides of the plate to prevent leakage. Either skip this position or drill a new hole nearby.

I used a framing square as a fixture on the drill press table to help position a round plate for drilling (*Photo b*). It ensures the holes are drilled in a uniform circle. Reposition the square for each drill size. If you leave the orifice plate square, you will have to manually reposition the plate for each hole. After you have drilled the holes, lightly sand both sides of the plate to remove any burrs around the holes. Hold the plate up to the light to confirm each hole is open and burr-free. The orifice plate is now ready to use.

This orifice plate has eight 1/16" holes within the inner green ring, 24 1/32" holes between the green and red ring, and 24 No. 74 holes barely visible between the two red rings. The smallest holes allow measurements at lower leakage rates. The holes should be spaced about ¼" apart to prevent airflow interference between them.

When making a round orifice plate, a framing square clamped to the drill press table helps align and drill the holes. A small adaptor (inset) is mounted in the regular chuck to be able to hold and use the small drill bits.