Benchless Head Porting

story, photos and illustrations by david vizard

Increasing Cylinder Head Airflow without the Aid—or Cost—of a Flowbench

Although it is currently accepted that a flowbench is needed to port cylinder heads, this has not always been the way. Before Superflow introduced their small 110-model flowbench some 30 years ago, probably 95 percent of the heads in use were ported without the aid of a flowbench.

Although this might make it sound like a flowbench—a device that measures airflow resistance through a cylinder head—is not an essential tool, the truth is that of those heads so produced, 90 percent were probably substantially less effective than they could have been.

While flowbenches can produce optimum results, however, they can be expensive. For that matter, the services of a pro head porter can also be expensive. The good news is that there are some cost-effective shortcuts that can help you produce your own ported heads.

A Little History

I flow tested my first heads back in the late '50s with a primitive homemade bench, which demonstrated many universally functional moves toward increased airflow. By the end of the '60s, I had a very sophisticated self-built bench that would give me cfm numbers to within better than one percent.

Where is all this leading? Simple: The tools required to port heads do not require a big investment, but the equipment to test the final results does. Given the right guidance and some basic rules, you can port your own heads to good effect for pennies on the dollar compared to the prices a pro will charge.

What I am going to do here is tell you what easy moves are the most likely to deliver increased airflow. This will allow you to work on your own heads and get, at almost no cost, about 50 to 75 percent of the increase one could reasonably expect from a pro with a flowbench.

Five Golden Rules

First, there are five rules that I give to performance professionals. They are simple, but it is critical to your success for you to absorb them. I'll list and expand on them a little.

Rule No. 1: Give the air room to move where it wants to go—not where you think it should go.

A significantly greater proportion of the air moves along the roof and long side turn of the port from mid to high valve lift. This means that grinding on the port floor is usually a step backward.

The Five Golden Rules of Head Porting

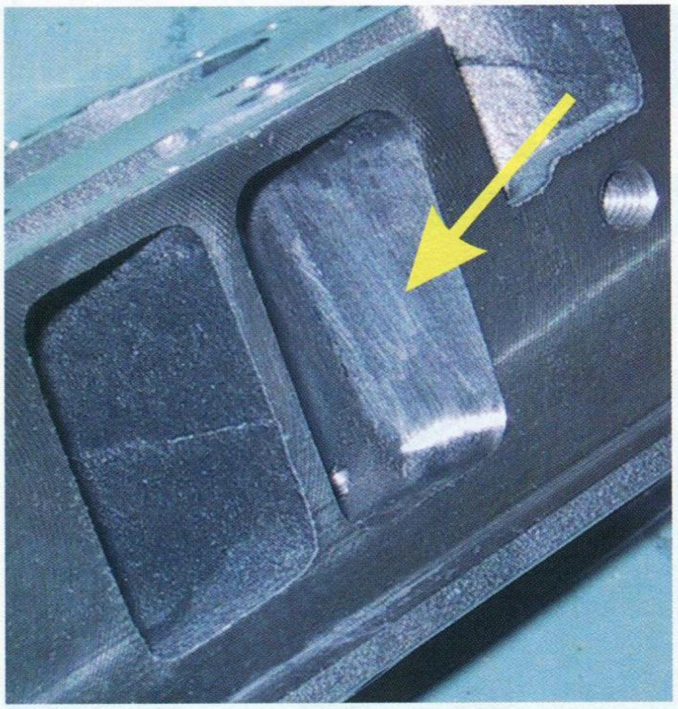
Rule #1
Give the air room to move where it wants to go - not where you think it should go.

Rule #2
Identify the points of restriction and fix them, as far as possible, in the order of severity.

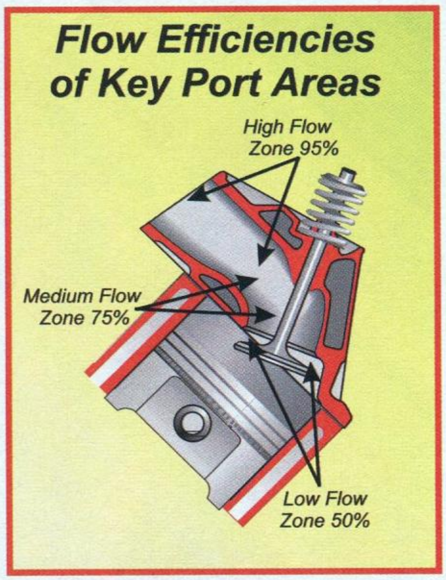
Rule #3
Charge motion at the point of ignition is important. It increases burn rate and reduces octane requirement.

Rule #4
High speed ports with minimal redundant port volume tend to result in better mixture quality.

Rule #5
If the breathing capability of the motor is limited at the rpm involved the CR takes on greater importance.



Above: The port entrance is almost always the first place a novice porter starts. This area is in the least need of attention. Right: You need only study this drawing minimally to see where the real restrictions to flow within an engine occur.



Whatever you may currently think, air is heavy and wants to travel in straight lines as far as possible.

Rule No. 2: Identify the points of restriction and fix them, as much as possible, in order of severity.

This, you would think, should be self-evident, but judging from the number of mistakes I see in home-ported heads, it must not be the case. We will deal in detail later with the primary restriction points that can normally afflict heads.

Rule No. 3: Charge motion at the point of ignition is important, as it increases burn rate and reduces octane requirements.

Swirl, tumble and squish, from the close approach of the piston to head quench area, are critical to overall performance.

Rule No. 4: High-speed ports with minimal redundant port volume tend to result in better mixture quality.

The air does not move with uniform velocity all over the port area; there are high- and low-speed areas. Enlarging the port at a low-speed area gains nothing and is often counterproductive. For the best mixture quality (carbureted applications) and inertial ramming effect, the ports need to have a high velocity consistent with the flow demands made of them.

Rule No. 5: If the breathing capabilities of the engine are limited at the rpm involved, the compression ratio takes on greater importance.

Any restrictions in the induction that cause the engine to suffer a reduced breathing efficiency (Volumetric Efficiency, or VE) mean that the compression ratio steps up in status from "important" to "very important."

Identifying Restrictions

With rule No. 1 always in mind, we can move directly to the application of rule No. 2 and expect positive results. But first a caution: When, without guidance, a novice head porter starts on a head, he or she will almost inevitably grind an area that is easily accessible, such as the intake runner at and near the manifold face of the head.

Here is something to think about: If you can easily access it, it probably was not in dire need of modification.

Let us consider the intake port shown in the accompanying drawing. Here we can see that the port entry is, in effect, a straight pipe. Therefore, we could expect its efficiency (what it flows divided by what it should flow if it were perfect) to be high—which it is.

As the port starts to turn into the bowl area, the efficiency drops off. When the air reaches the valve, it encounters the most un-streamlined form in the entire air passage through the engine.

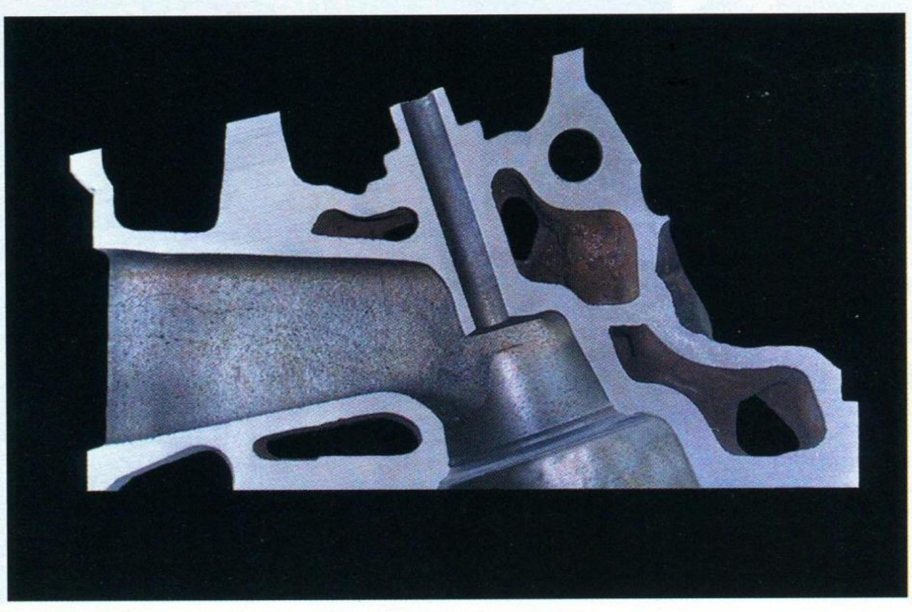
From this, you can see that there is, in most cases, little to be gained from modifying the port in a high-efficiency area until the most has been made of the worst. This applies to both the intake and exhaust and brings up the subject of pocket porting.

Pocket Porting

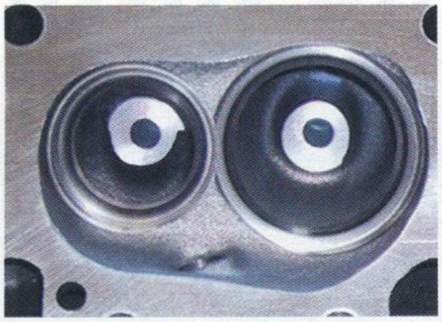
Pocket porting is often viewed as the budget-constrained racer's alternative to a proper porting job. The truth of the matter is that pocket porting, which involves reworking only those areas immediately adjacent to the valve seats, returns excellent dividends in terms of airflow gained per dollars or time spent, as this method seeks to remedy the worst-flowing parts of the cylinder head.

Pocket porting a cylinder head is an almost fail-safe way to increase performance, as it entails blending the throat of the port into the valve seats with a smooth radius form.

Before beginning the blending process, you must give some consideration to the seats themselves, as the immediate approach to and departure from this part of the cylinder head is critical to low- and mid-lift flow. The velocity between the valve seat and head seat is higher than that seen in the port until



This sectioned head is typical of many two-valve designs in that the guide boss is intrusive. Shortening the boss is not the answer, as it leaves the valve with less support. This means the air must be given clear passage around the sides of the guide boss.



the valve reaches a lift value of about 20 percent of the valve diameter. In other words, for some 50 to 60 percent of the valve's lift envelope, the seat is the primary restriction to flow.

First, identify where the valve seat is on the valve. Many production head seats are significantly smaller than the valve. To establish how much smaller it needs to be, lap the valve onto the seat until it colors up, and then look to see where it falls on the valve. The seats often can be beneficially re-cut.

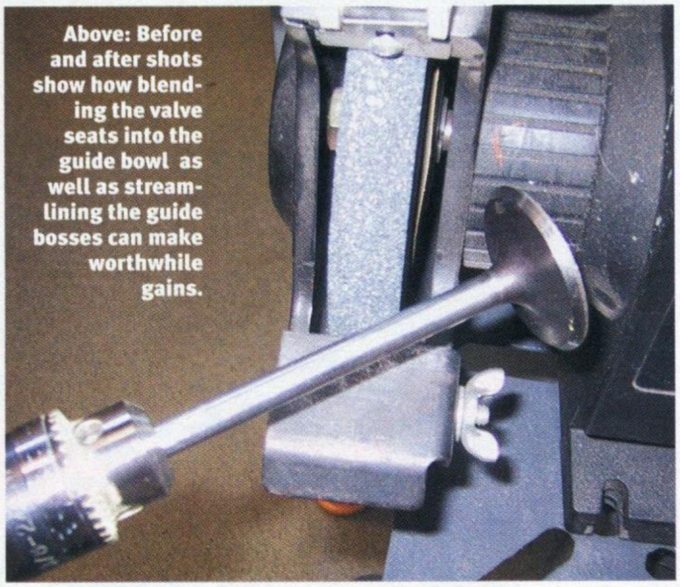
The simplest effective valve geometry is to have the seat in the head some .005- to .010-inch smaller than the valve head. This should be top cut about .015-inch wide with a 30-degree cutter. The area immediately under the seat needs to be cut with a 60-degree cutter. Blend this into the remaining part of the port, leaving a band of the 60-degree cut about 1/16-inch wide.

If the head seat is close in diameter to the valve seat, then just go ahead and blend the seat to the throat, bearing in mind that the key to success here is no sharp edges. Be sure you make the short side turn as generous and smooth as possible, as this will help the air go around the corner and delay the inevitable flow breakaway that occurs until higher lift is reached.

If the valve lift being used is more than 20 percent of the valve diameter, then the flow can benefit, at higher lift values, from streamlining of the guide boss. The trick here is to skinny down the guide boss so that air can pass more easily around each side. This move increases the airflow from high/mid up into the high-lift range.

When you have successfully completed this, congratulate yourself on achieving a deep pocket porting job. However, this is not the end of the line. The next major impediment to flow could be valve shrouding, which we will consider in a moment.

Above: Before and after shots show how blending the valve seats into the guide bowl as well as streamlining the guide bosses can make worthwhile gains.



Valve Preparation

Almost all valves, including high-performance, aftermarket ones, are produced without the benefit of a detailed form to maximize flow. Some really easy air can be gained by simply back-cutting the valve to blend the under-head face into the seat.

For those with access to a valve seat refacer, this is easily done by cutting a 30-degree backcut on the valve so as to narrow the 45-degree seat on the valve to match the width of the head seat.

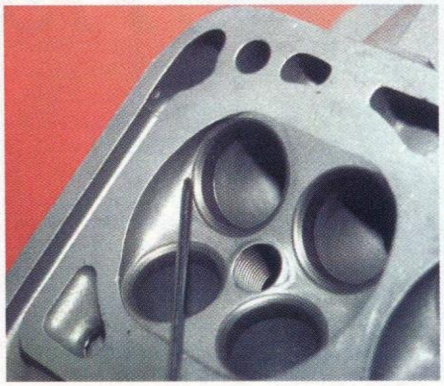
However, lacking that equipment, the process can also be easily achieved using an electric drill and an offhand grinder. It is also a good idea, especially on the exhaust valve, to radius the front face of the valve into the edge, as this allows gases to easily flow around the valve head at low lift, thus boosting flow.

Back-cutting the valves is about the cheapest and simplest move that can be made to increase airflow. Do not fail to include it any time the head is stripped.

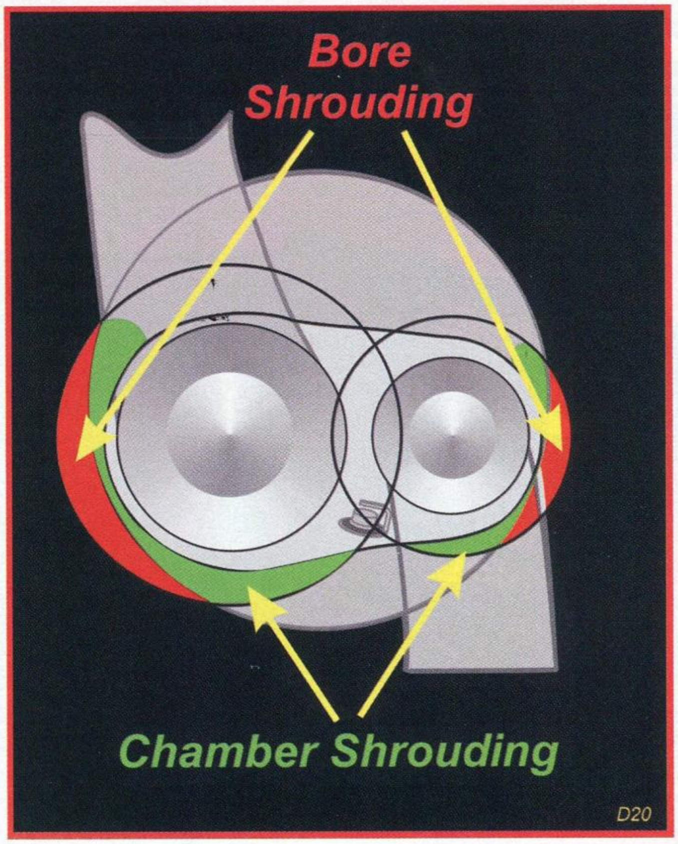
Valve Shrouding

One of the reasons hemi valve combustion chambers were popular with aircraft engine designers is that they have no valve shrouding, promoting better flow. The same cannot be said for parallel or nearly parallel valve heads. Indeed, even four-valve heads have some valve shrouding.

As shown in the illustration, the circles around the valves have an area, from the edge of the valve to the circle, equal to the valve head itself. Anything that falls within this circle is shrouding the valve,

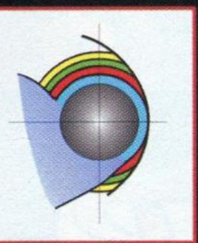


Even four-valve heads can have shrouding. This occurs at similar points around each valve as indicated here.

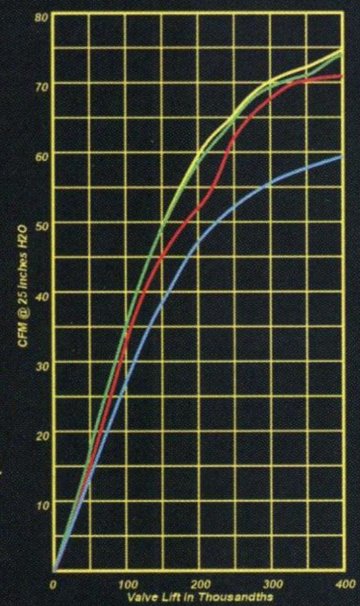


In this drawing, which represents a typical wedge-shape, two-valve combustion chamber, the shrouding caused by the cylinder bore is shown in red. This we can do little about. Shrouding caused by the combustion chamber, shown in green, is another matter.

Deshrouding Test - 850 Mini Head



Above is a view of the area around the intake valve. The blue line on the graph is for the stock chamber with the severe shrouding seen above. The wall around the valve is approximately 0.68 inches rad. When the red area is cut away (0.80 inches rad) the flow increased to that shown by the red line on the graph. The graph's green and yellow lines represent the green and yellow areas cut away. Note the law of diminishing returns is working here.



thus reducing the through-flow passage area into the cylinder.

Some of this shrouding is inevitably caused by the proximity of the cylinder wall (shown in red), and little to nothing can be done about it. Shrouding caused by the chamber (shown in green), however, is a different matter. Assuming the casting has enough thickness, this can be removed as long as it does not compromise the achievable compression ratio.

How much of an effect this removal of the shrouding has on the flow varies from head design to head design. Also, it is important to understand that the removal of the shrouding only pays off if the air wanted to go that way in the first place.

For the most part, deshrouding the area around the valve adjacent to the long-side turn (where most flow exists) pays off the best. Indeed, deshrouding the area adjacent to the short-side turn can also reduce swirl and, sometimes, flow. In the absence of a flowbench, it is best to play it safe and deshroud around the valve on the long side only.

So, how much is deshrouding worth? That really depends on how bad it was in the first place, but a test I did on an 850cc A-series engine as used in a Mini is well worth a look. The first band was cut back 1/8-inch, and from there on each subsequent band was cut back 1/10-inch. The first cuts yielded the biggest gains.

How much does the chamber need to be cut away to unshroud a valve? A simple rule of thumb is that the chamber wall needs to be away from the edge of the valve by an amount equal to about 90 percent of the valve lift. This means at .020-inch lift, the chamber wall should be about .018-inch from the edge of the valve. At .050-inch, the valve-edge-to-chamber-wall figure should be .045-inch.

But all this makes the assumption that the flow efficiency of the valve itself is good. If it is not, then cutting away the chamber to make room for nonexistent airflow is pointless. Again, we come back to the fact that care taken on valve seat preparation is a pivotal factor toward success. Even in a worst-case scenario, figure cutting away the chamber to 80 percent of the valve lift. Remember, though, that this should be done only on the long side and again only if you know the chamber wall thickness is adequate.

Shrouding around the exhaust is not the great issue it is on the intake. If the shrouding exists on the chamber wall adjacent to the exhaust-port, short-side turn, do not be in too much of a rush to remove it. Doing so can often reduce flow at high valve lift, because the air coming in from this side interferes with that flowing on the long side.

The Exhaust Port

Much of what is true of the intake ports also applies to the exhaust. After the valve seat, the short-side turn is the next most important area.

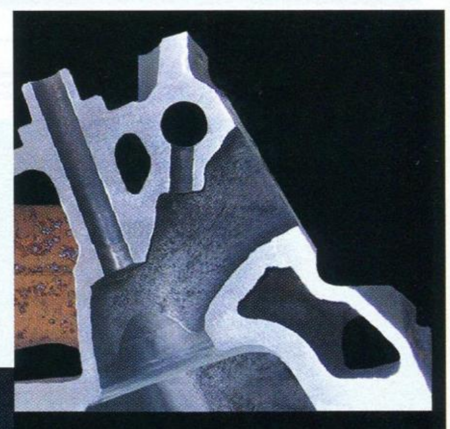
The size of the radius joining the seat to the port can be much smaller than on the long side to achieve good effect. On the long side, look to make the radius about .100- to .125-inch if possible, but on the short side, this can be as little as .025-inch.

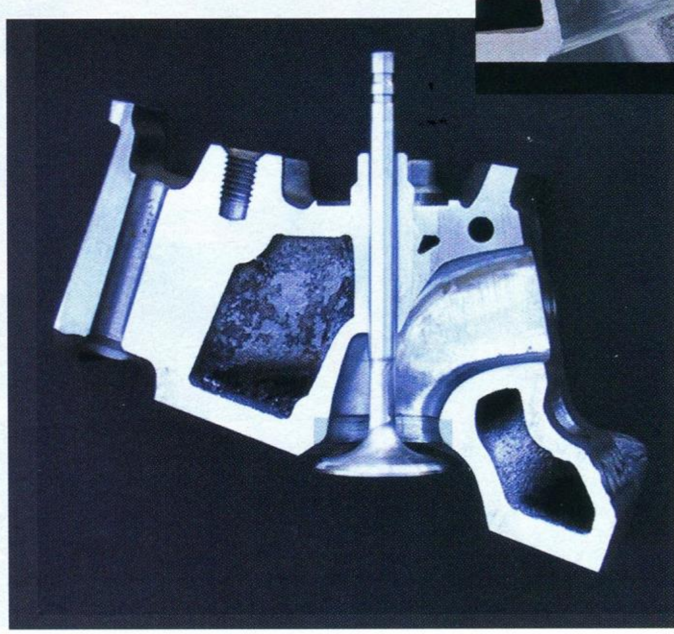
After reworking the area adjacent to the valve seat, move down and put the guide boss on the same slimming diet as you did the intake. Do not be tempted to shorten the guide or boss unduly, as this will raise the temperature of the head of the exhaust valve.

The exhaust ports of production heads often have EGR bosses cast into them. These are inevitably ugly protrusions which almost always cut flow from about .200-inch on up. These can be easily removed, but the hole still remains.

Do not concern yourself with the fact that there is a hole in the port, as this has virtually no effect on the port flow. Even those big exhaust crossover passages, such as one finds on V8 Chevy head castings, have minimal effect, which is surprising considering their size.

Do not remove metal from the port floor even if it does not match the port in the exhaust manifold. It is far better to have a step here than to create a dead or low-speed zone. Once past the guide boss, concentrate on





Above: Many production exhaust ports, especially those with air injector ports, can get ugly. Cutting away the offending intrusions can pay big dividends.
Left: Here is the exhaust port shape you're shooting for. Avoid removing metal from the floor of the port and be sure to concentrate on a smooth shape for the short side turn.

the roof of the port, but do not hog it out in the belief that bigger is better. In the interests of maintaining a good port velocity to aid chamber scavenging and to promote a good power bandwidth, keep the port small. If possible, limit the port size to about 110 percent of the area of the exhaust valve.

Finishing Your Porting Exercise

Here's an overworked phrase that is often thrown around in discussions of cylinder heads: "ported and polished." The polish does little to nothing.

So long as you remember that form is all-important, then you will be happy with the results. I rarely use emery rolls of finer grit than 80 and most commonly use 60 grit. When worn, these will produce an entirely satisfactory finish on your heads.

Once all of the porting work has been done, it's time to cc the heads and have them machined on the face to deliver the compression ratio required. A parting hint here is that the higher the compression ratio the better, as long as detonation does not rear its ugly personage. GRM

David Vizard has been involved in motorsports for more than 40 years as a driver, car builder and journalist. To date, he has written 29 books on the subject, covering topics from the BMC A-series engine to the small-block Chevy. He currently races a Ford Mustang in NASA's American Iron class.

Tools for the Job.

To port cylinder heads, you will need an adequately high-powered die grinder. Unfortunately, those little 1/8-inch shank-style electric grinders won't make it unless you plan to port a 50cc Honda head. If you have a compressed air source of more than 7 cfm capacity, then the cheapest option is an air grinder.

I have tested a number of cheap air grinders, and the model with "Excell" cast into the body has proved to be the best to date. Cost is typically about $20 at your local home improvement store, and this unit runs about 22,000 rpm on 100 psi. For much of the work, you will need to slow the unit down, so add the cost of a pressure regulator and water separator to the bill. (Expect to pay about $30 to $35 for these items.) Be aware that if you go the compressed air route, it will mean the electric bill can be as much as five times more expensive compared to an electric die grinder.

If electric is your choice, then the DeWalt grinder is about the lightest industrial-grade unit you can get. It is a little more powerful than an air grinder, so it will deliver higher metal removal rates. Unfortunately, it is more bulky to use.

Electric die grinders of this type generally run about 20,000 rpm. To regulate their speed, use a light dimmer switch rated at or above the amperage rating of the tool.

Your selection of cutting tools is critical if the job is to be completed before you lose patience. High-speed steel tools are inadequate for either aluminum or cast iron; the only type of tool for the job is an industrial-grade carbide.

Even then, getting the best tool for the job is a little more complicated than paying a visit to your local tool store (where you could pay up to twice the price). I can recommend two sources here, and both offer cutters with tooth designs explicitly designed for porting heads: Cylinder Head Abrasives and Roger Helgesen. Both outfits are located in California. Cylinder Head Abrasives has been in the cylinder head business for a great number of years and can supply not only a useful range of cutters but, as a major dealer for Standard Abrasives, they can also be your source of emery rolls and the like.

Roger Helgesen is a cylinder head and intake manifold development specialist. Apart from porting heads and manifolds, he also designs and develops porting tools and cutters. So in addition to other porting tools, he has a very effective range of cutters available at very competitive prices.

As far as emery rolls and disks are concerned, it is best not to buy the "all in one" porting kits. In my experience, these usually have too few of the items you need and too many of those you don't. Figure you will need one short and one long mounting arbor and about 20 to 25 60-grit emery rolls that are 1/2-inch in diameter by 1 1/4-inch long for a typical four-cylinder head.

You will also need a 1-inch diameter flat disk arbor and about 25 to 30 80-grit disks. None of these abrasives will give your head a polished finish, but as I pointed out earlier, it is shape, not shine that produces power.

Sources

Cylinder Head Abrasives
(800) 456-5474
www.ruffstuff.com

Roger Helgesen
(310) 323-1859

Standard Abrasives
(800) 383-6001
www.standardabrasives.com

If you have a source of compressed air of more than 7 cfm per minute, then an air-powered die grinder may be the way to go. These can be purchased very cheaply at your local home improvement center.

Of the industrial-quality electric die grinders, the DeWalt is among the lightest and is certainly not the most expensive.

For most applications, the two 3/8th olive cutters seen here will be all that is needed. If you intend to cut cast iron, be aware that a finer tooth form is needed than for aluminum. WD-40 makes an acceptable cutting fluid, but if you want a super cutting fluid that even allows cast iron cutters to be used on aluminum, call Roger Helgesen.

Standard Abrasives has a wide variety of products for the cylinder head porter. Their catalog is almost a must.