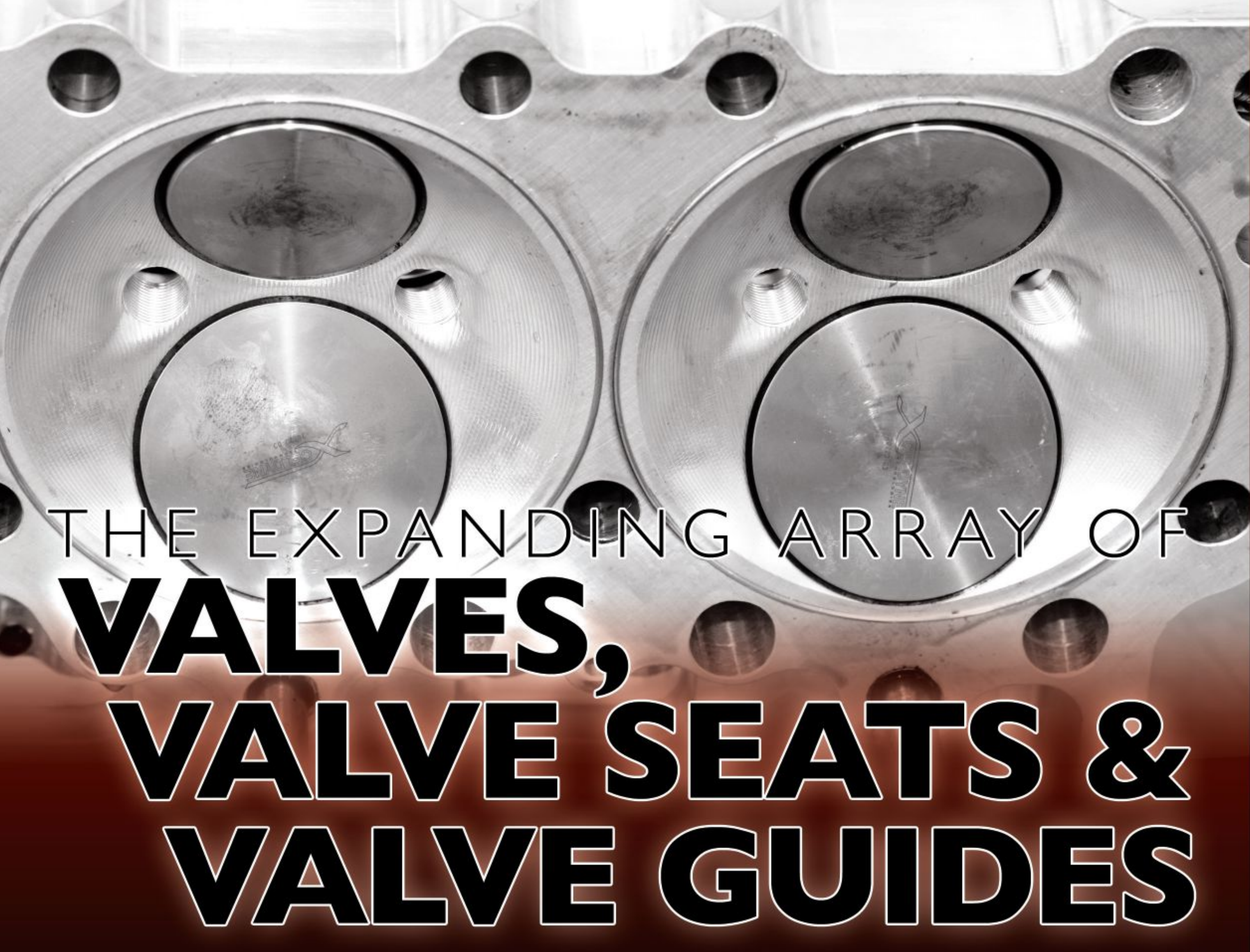

THE EXPANDING ARRAY OF

VALVES, VALVE SEATS & VALVE GUIDES

EXAMINED closely, a race engine valve is an astonishingly complex three-dimensional form. The cylindrical stem itself can vary in diameter, and may or may not be back-cut before it flares out more or less suddenly to form the head. Even so, the back of the head can be more flat or more conical. The seat angle is generally (but not necessarily) 45 degrees, and the margin below the seat can be thicker or thinner, and cut sharp at the bottom (to discourage inlet tract reversion) or rounded over (to encourage exhaust flow). And we're sure we've missed a variable or two.

"We constantly strive to design better-flowing valve profiles, throughout all of our valve lines," said Daniel Urrutia Jr. of Ferrea Racing Components, Fort Lauderdale, Florida. "Today's cylinder heads require increased flow numbers—and that trend will continue for the foreseeable future. So we have invested in new equipment and software to aid in the hundreds of calculations that go into simulating the interaction of fluids and gases. The variable three dimensional surfaces of a racing engine valve play a fundamental role in maximizing a cylinder head's flow capability."

That increased performance, however, places ever-higher demands on durability—further driving geometric sophistication and complexity. "For today's racing engines worldwide," noted Don Weber of Engine Pro, Wheat Ridge, Colorado, "valves are becoming more and more complex—due mainly to constant increases in power, more turbo boosting, higher rpm and extra-dry fuels with additives. It is very difficult for a race valve to survive in such a mechanical and thermal environment—forcing manufacturers to push the envelope with new alloys, new coatings, new forgings, and new machining processes."

And that envelope just keeps on getting pushed harder. "In just the last two years," added Ed Doyle of CHE Precision in Newbury Park, California, "this situation has been exacerbated more than in any of the years that I've worked in the industry. The last two years have seen really big developments."

Many of these developments are covered in the following pages.

The Physics of Flow

Later on we'll take a look at some of the technical advances that are making today's racing valves tougher and more durable than ever. First, however, let's look at how variations in the geometric shape of the valve can help or hinder flow through the port.

"One thing is certain in all engines," commented Willy Tagliavini of Supertech Performance, San Jose, California, "the smaller the stem diameter, the higher the flow rate."

BY JOHN F. KATZ

Manufacturers of race engine valves, seats and guides share their latest product developments, and what to expect in future valvetrain components.

Because of ever-increasing demands on durability, today's race engine valves are becoming more complex and sophisticated, according to our sources. In fact, greater power production and alternative fuel blends are just a couple of the factors driving valve manufacturers to develop new alloys, coatings, forgings and machining processes. Photo courtesy of Supertech.

After that, however, things get more complicated. "The shape of the valve head is very much related to the shape of the ports," Tagliavini continued, "and to the position of the valves in the combustion chamber. But there is more than one way to resolve flow issues." Flat-headed, nail-like valves, for example, "usually don't produce good flow rates, and are most often used for weight reduction. But a strategically located ridge below the seat face can produce turbulence, simulating a steeper angle between the head and the stem, and actually promoting better flow." Intake valves, he added, "are more sensitive to flow rates, and in some cases feature up to four different back angles between the seat and the stem." Turning to the face of the valve, "a dished face can save weight, especially if the valve has a deep cone where the head meets the stem. But a dished face can also affect flow and even combustion by creating a low-pressure area where fuel may condense."

It's precisely this kind of complexity, observed Mike Perry of Kibblewhite Precision Machining, Pacifica, California, that encourages application-specific design. "For example, say we're designing a performance intake valve for an OE head. We'll start by flow-testing the factory valves to establish a baseline. Then our custom shop will make samples with different back-cuts, tulip profiles, and radii; and we'll flow-test them. We may find that an intake valve with a flatter profile works better than one with the stock profile, but that it needs one or more back-cut angles to optimize flow. If we can improve flow characteristics with a flatter profile, then we've also reduced mass and increased the overall performance potential of the engine."

Intake and exhaust valves are not necessarily symmetric. "It's not uncommon to find that the engine combination likes an exhaust valve with a steeper profile and a larger radius than what is used on the intake," Perry continued. "You may also find that you want a fairly sharp edge on the margin of the intake valve to help prevent reversion; and a rounded edge on the margin of the exhaust valve to promote flow around the head and out into the port.

"Now we have to examine the possibility of machining a dish in the chamber side of the valve, to keep the mass under control. But then we have to look at dish volume and its ramifications for the compression ratio. Once the optimum shape has been determined for each valve, our engineers run the design through our Finite Element Analysis (FEA) software and look for the areas of greatest and least stress, to determine where material may be able to be removed for weight reduction, or where it may have to be added for strength," he concluded.

Milodon in Simi Valley, California, offers its Megaflow racing valves, which feature Stellite tips hardened to 58–80 Rc and undercut stems for improved flow, according to Ken Sink. These one-piece forged valves are made from premium quality 21-4N stainless material. "They aren't the lightest valves out there, but they're super strong," he said.

In addition, the Megaflow valves are swirl polished for increased flow and have tulipped valve heads for weight savings. They are compatible with either seven- or 10-foot retainers.

These valves have been used on modifieds, Late Models, blown big blocks and more, Sink noted.

Scott Highland of Xceldyne, a proprietary brand of CV Products, Thomasville, North Carolina, also noted how profiles can differ between intake and exhaust valves. "Generally an intake valve might see a 30 degree plus-or-minus back-cut above the seat area to enhance flow; where on the exhaust the benefit of this would be nominal. Another example is the radius of the transition from the valve face to the margin, which enhances flow past an exhaust valve. However, on an intake valve a sharp corner is preferred for flow improvement."

Urrutia further explained how "engine valves can be tailored to maximize the cylinder head's flow design." Port design,

"For today's racing engines worldwide, valves are becoming more and more complex—due mainly to constant increases in power, more turbo boosting, higher rpm and extra-dry fuels with additives."

combustion chamber configuration, air distribution in the intake manifold, camshaft timing and lift, and engine speed all influence the ideal valve diameter and head thicknesses—including the margin, seat, back-cuts, profile angle, and radii." High engine speed reduces the amount of time that a valve is open, so "the timing sequence makes every little detail of the valve's profile that much more important to maximize flow during the narrow window that the valve is open."

As an example, Urrutia pointed to the custom valves Ferrea makes for Pro Stock. Depending on individual team requirements, back-cut angles may be 23, 35 or 45 degrees, "trailing off a 10–12 degree back-angle and leading to 50 degree valve seat, with widths ranging between .050 and .070 inch in order to maximize cylinder fill rate. The valve head radius, back-angle, and multiple other angles help change the airflow direction smoothly around the head and into the combustion chamber," he said.

Seat Angle

Of all these various dimensions, we found particular attention paid to seat angle. "One of the trends we've noticed over the past year," reported Michael Tokarchik of Manley Performance Products, Lakewood, New Jersey, "is the change in seat angle, from the traditional 45 degree angle, to a greater angle of 50, 52 or even 55 degrees. These angles are being explored by our customers to enhance airflow at higher lifts. And as a manufacturer, we have no concerns about making valves with those different seat angles. But we have noticed that, in the field, customers are experiencing seat recession at angles greater than 45 degrees. The change from 45 to 50 degrees doesn't seem to be that problematic, but once you get to 52 degrees on titanium, you really need to consider a seat-face coating. You can mitigate seat recession with a Chromium Nitrate (CrN) coating. But at 55 degrees, in some applications, we're noticing premature seat recession even with the CrN coating. And this is due to the fact that, given the same seating force, as you increase the seat angle, the unit loading also increases significantly. And the unit loading is what causes the substrate, the titanium itself, to deform. Even though the CrN coating is very hard, it's very thin; and the titanium below it deforms, causing rapid seat recession."

"There are several newer port designs that respond well to steeper seating angles," Perry confirmed. "It is not uncommon now to see 50, 52 or 55 degree valve faces and corresponding seat angles. These angles are typically associated with full-on performance applications—which usually incorporate titanium valves, very aggressive cam profiles, high rpm and lots of spring force. In some of these combinations, these steeper seat/face angles can see rapid seat or face deformation. This has led to the increased use of hard coating on titanium valves to prevent the faces from pounding out."

Valve seat manufacturers are also concerned. Doyle explained that, as the valve face angle increases—he's seen angles as high as 60 degrees—the face itself narrows, which increased the unit load per square area. So CHE Precision is "developing better materials that can withstand these high unit loads—especially for the Fuelers, because they can destroy anything on a good day, let alone bad one. We have our own proprietary material"—which should be available by the time you read this—"and it will be superior to the beryllium-copper and other materials that have been in use."

Highland, on the other hand, seemed less concerned. He said, "We continue to observe steeper intake seat angles to enhance airflow. Thin film coatings such as PVD and PACVD have allowed this technique to work without accelerated wear."

To some extent, the urgency of the problem depends on application. "It is not the same dealing with a drag racing application that only needs to

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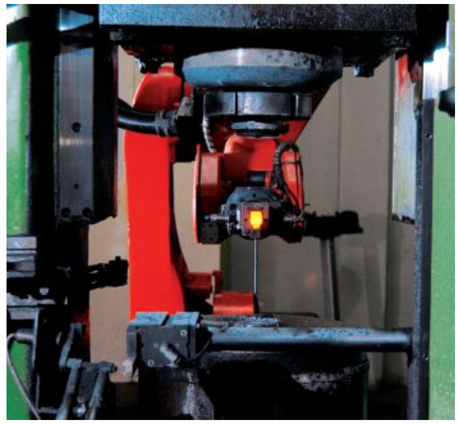
run for several passes," said Weber, "versus an engine for the 24 Hours of Le Mans—or a spec engine designed to run for an entire season. It's always a compromise."

Nonetheless, according to Tokarchik, "the trend is starting to reverse. The customers who went from 45 to 50 to 52 to 55 degrees are now backing up to 52 degrees, or sometimes 50, because they are realizing that the incremental gain in airflow is not worth the accelerated seat recession." These customers are also realizing that seat recession compromises performance as well as reliability: "Because you lose sealing in the combustion chamber, you're down on power." So when choosing a more radical valve seat angle, "you might see an initial, incremental increase in power; but in short order you'll see a decrease in power because you are not sealing the combustion chamber efficiently."



Variations in the shape of a valve can have a substantial impact on flow through the port. For example, flat-headed, nail-like valves "usually don't produce good flow rates, and are most often used for weight reduction," said one source. "But a strategically located ridge below the seat face can produce turbulence, simulating a steeper angle between the head and the stem, and actually promoting better flow." Seen here is an Engine Pro valve just before being stamped at the forging press.

Seats & Guides

With or without high, non-standard valve-seat angles, the durability of valve seats and guides continues to improve. Chuck Barnett reported continuing success for Dura-Bond's Killer Bee "copper-infiltrated" valve seats. Using a process developed by GM and Federal-Mogul, the Carson City, Nevada-based company applies a thin layer of copper to these powder-metal valve seats after pressing but before heating. The copper melts into the seat, where it improves heat transfer between 4 and 6 percent. "Some of the performance manufacturers are going to use our Killer Bee seats on both the intake and exhaust side," Barnett continued, "in GM LS engines, and in the Chrysler Hemi, where there have been some problems. We can't say who, but that includes a major player."

For another potentially expanding market, Dura-Bond has developed "a

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more robust seat" for natural-gas-powered applications. And now the company is investigating powder-metal valve guides. "Ours are in the preliminary stages," said Barnett, "but the OEMs use powder-metal guides in 90 percent of their heads—especially in aluminum heads. They need the tighter tolerances for emission control"—and they need lubricity from the material itself, rather than relying on oil. Barnett believes that powder-metal technology will significantly improve valve-guide life in racing applications.

The shape and length of the valve guide is also significant, as these factors can influence flow through the port. "We can improve the flow characteristics of the port by re-shaping the nose of the guide," said Perry. "However, we still have to balance how the nose shape affects airflow against the required cross sectional area for stability and durability. A narrow, streamlined guide may work great in an intake port—and flow well in the exhaust port—but the exhaust guide may need a thicker cross-sectional area to withstand the additional heat."

"Usually the guide isn't even in the port anymore," added Doyle. Unfortunately, engine builders are specifying shorter valve guides at the same time that they are building for higher and higher valve lifts—"and a guide that is not as long tends to wear faster. So we're trying to go longer the other way. And we are looking for new materials. We have a proprietary material that we developed about five years ago, and have so far used strictly for Pro Stock, that we are going to start using for other forms of racing."

Statics & Dynamics

As we mentioned at the outset, the shape of the valve not only influences flow through the port, but the structural integrity of the valve itself. "Much depends on the design of the cylinder head," noted Chad Elliott of Roush Yates Performance Products, Mooresville, North Carolina, "but generally speaking, the back-cut angle increases in proportion to the seat angle. In contrast, the profile radius is inversely proportional to the seat angle, that is, the steeper the seat angle, the larger the profile radius, representing a trade-off between strength and flow rate. The balance struck is almost as diverse as the number of people designing cylinder heads and valves. There is no free lunch here: Adding seat and profile angle will increase flow through the port, but adds weight to the valve, and requires more maintenance for the cylinder head and valve."

Gordon Johnstone of Scorpion Racing Products, Ocala, Florida, identified three areas as "critical" for airflow and weight savings: "the area of the valve stem just above the valve head; the radius that connects the valve stem to the valve head;

and the thickness of the valve head." Unfortunately, he added, "these are areas that also need to be rigid. When the valve changes direction, a flex or whip occurs between the valve head and the stem, especially on valves with larger heads. Naturally the end result could be failure"—but long before that, a valve head that is moving relative to the stem will not seat properly as the valve closes. "Our engineers have concentrated on increasing rigidity in these areas without adversely affecting weight or airflow. We use 21-4N material for intake valves and 23-8N for exhausts, as these materials have proven most durable for the varying temperatures and stresses involved."

Perry provided another example: "For decades it's been common to see an area on the valve stem just above the tulip that was reduced in diameter. But with the trend toward smaller-stem valves to reduce mass and increase rpm, rather than incorporate this thinner 'waist,' we've actually designed an expanding taper on some small-stem valves to increase the cross-section and strength in this highly stressed area."

Weber emphasized how "heat treatments are at the heart of trouble-free valve operation. The goal is a very ductile valve that can withstand accidental contact with the piston." A valve that bends instead of breaks allows the driver to stop the engine before it is destroyed by a loose piece of valve. "At the same time, depending on engine use and class, you need good durability between teardowns, this in certain cases can be several thousand miles, or several months. Again, the final solutions always come from compromise."

In the past year Ferrea has begun to use new materials for both intake and exhaust valves, "such as X85 valve steel," said Urrutia, "designed specifically for intake applications, where light weight is required, while retaining high tensile strength and good fatigue characteristics. Using X85, we have been able to

In addition to valve makeup, the shape and length of the valve guide is significant, and can also impact flow through the port. "We can improve the flow characteristics of the port by re-shaping the nose of the guide," one contact explained, "however, we still have to balance how the nose shape affects airflow against the required cross sectional area for stability and durability." Photo courtesy of Kibblewhite.

reduce the cross-sectional thickness of our intake valve heads approximately 20 percent relative to an equivalent-size valve manufactured from EV8." Also in the past year, Ferrea has begun using Ni30, "a high-temperature stainless for exhaust valves in supercharged and turbo applications. We consider Ni30 a semi-super alloy for its resistance to exhaust temperatures ranging between 1400 and 1600 degrees F." Ni30 also contains added iron for exceptionally long wear.

Forced Induction

Indeed, strength and temperature resistance become even more critical in forced-induction applications. "Forced-induction applications are obviously exposed to greater temperatures and pressures," said Highland. "So we are introducing a steel valve line called X2, which will feature nickel-based alloys such as Inconel and Nimonic, which provide the mechanical properties needed to survive in these harsh conditions." Meanwhile, CV Products' existing Xceldyne brand will "continue to add to its available shelf-stock product line, and expand its short-lead-time custom program."

"Higher engine temperatures due to turbocharging and supercharging often require different materials," said Phil Martin of Del West USA, Valencia, California. "In these circumstances, we may have to move away from the more traditional steel and titanium alloys to nickel-based alloys (Nimonic or Inconel) and to intermetallic compounds such as titanium aluminide. Unfortunately, the rules of various series often play a defining role in what materials may be used."

It's worth noting, Weber added, that valves "in turbo and supercharged applications do not always require exactly the same approach. Turbocharging imposes even higher thermal loads on the exhaust valves due to early opening. Generally speaking, however, both intake and exhaust require high-temperature-resistant nickel alloys such as Inconel."

And according to Tagliavini, intake valves in turbo or supercharged applications "do not differ much" from their naturally aspirated counterparts, "because the valve is always being cooled by a new, fresh charge of gas. But hot exhaust gases increase the temperature of the exhaust valves considerably. For this reason, exhaust valves in these applications differ from intake valves in both shape and material. The seat is wider, for example, to provide better thermal transfer, and the back angles are steeper, to provide a more 'tulip' shape, which is more rigid." And, like most valve manufacturers, Supertech uses Inconel and/or Nimonic alloys in exhaust applications.

But even so, Tagliavini added, at the levels of boost that are becoming common today, "design and materials like those just described are no longer enough. One problem with high-boost engines is that the valves tend to warp and leak, loosing compression and power. So we recently introduced sodium-filled Inconel/Nimonic valves for the most popular turbocharged applications in the sport compact market. The hollow stem is 50–60 percent filled with sodium, which, at very high temperatures, becomes liquid and transfers heat from the head to the stem and away from the valve through the guide. The resulting temperature reduction will keep the material stronger and mitigate warping." Furthermore, lowering the temperature of the valve head gives the tuner more flexibility to advance the spark without risking pre-ignition. "An extra benefit is the weight reduction; it depends on the size of the valve, but averages 10 percent."

Lightening the exhaust valve not only improves performance, but also reduces impact load on the valve seat.

Polishing, Finishing & Coating

So what's next? "We've picked the low-hanging fruit," said Tokarchik. "We've made a lot of important gains over the past decade with both steel and titanium. But the gains that we are going to be making moving forward are going to be much more incremental. There are no radically different materials—stainless, nickel-based, or titanium—that we can foresee using. Instead, we are looking at improving the surface finish, using micro-polishing and micro-finishing to reduce the Ra well below what has been typical for race valves. On the stem, this will allow the use of hard coatings, which will reduce wear on the guide. And by micro-finishing the seating face of the valve, we can enhance the performance of a CrN coating—because the flatter the CrN coating, the less chance there is for micro-welding or material transfer between the valve seat face and the seat insert in the cylinder head."

Manley has expanded its titanium shelf stock to include more valves "ready to ship with the CrN seat-face coating already on them, so customers no longer have to order valves from us and then wait for them to be coated. And that expansion includes all the popular offerings, primarily for dirt late models and sprint cars. On the stainless side, we are offering replacement valves for the new LT1 engine; we have both intake and exhaust valves in our Race Series and Severe Duty lines."

"Surface finishes have continually improved," Martin agreed, "to accommodate the requirements of currently popular coatings such as CrN and DLC."

"There is a range of different hard coatings that can be applied to a valve to improve durability," said Tagliavini. "Examples include CrN, TiN, Moly Coat, DLC, etc., all applied to different areas of the valve to reduce wear and friction. Most of our stainless valves benefit from a nitride heat treatment we call Black Nitride. Like any nitride treatment, it provides a hard surface all around the valve that reduces wear, improves fatigue life, and provides a smoother surface with a lower coefficient of friction. That's very significant on the stem, where it reduces wear on the valve guide. In some cases it can reduce carbon build-up, too."

Improving surface finish provides other benefits as well. Johnstone said, "Over 30 percent of the heat that is conducted from valve to the cylinder head is transferred through the valve stem," which is another reason Scorpion valves feature a super-finished, hard-chromium stem.

Weber noted the importance of carefully handling valves after finishing and polishing, to avoid any metal-to-metal contact that might ding or scratch the stem before the valves are packaged for shipping. Engine Pro plans to expand its Nitro Black, Competition

Today's top manufacturers are constantly developing new valve designs—including custom services for teams and engine builders in countless different racing segments. In addition, improved surface finishes are allowing for the use of more hard coatings, which in turn reduces wear on the guide and enhances overall performance.

Series, and Street series lines to cover more Chevrolet LS applications, and later on Chrysler Hemi and "very possibly" Modular Ford engines as well, said Weber. "All of our valves are proprietary, manufactured exclusively for us in Argentina, in the same sophisticated facility that supplies OE valves for such sophisticated companies as Ferrari, Maserati, McLaren, Harley-Davidson, John Deere, Polaris and others."

Perry pointed to Kibblewhite's "custom services," noting how "a large part of our business is developing new valve designs for teams and engine builders. Kibblewhite's stainless steel Black Diamond valves have been run successfully in Suzuki Hayabusa engines in "open wheel racing, motorcycle drag racing, and land speed efforts." Kibblewhite also offers "variations" on valves for Harley-Davidson Evolution and Twin-Cam cylinder heads, involving "different head sizes, shapes, materials and lengths to accommodate just about any port and valve-size configuration."

The proliferation continues. Rely on PRI to keep you posted. PRI