THE PRECISION ENGINEERING OF VALVE SPRINGS & ROCKER ARMS

By John F. Katz

Ranking among the most influential components in the valvetrain, these products are maintaining their stability even in the face of today's wildest camshafts.

"Rocker arms are huge," proclaimed Kerry Novak of Crower Cams, San Diego, California. "The market is growing every day." Novak laughed when we countered that a classic racing V8 could only use 16 of them at a time.

What's driving the sales growth is advancing technology, and a plethora of new products arrayed against the daunting demands of higher lifts, higher spring pressures, and higher rpm.

"The latest trend is toward shaft-mounted systems," Novak continued. "And in the top classes—oval track or drag racing—we're selling more billet. It's because of the rpm, the spring pressure, the camshaft design—everyone wants the fastest-action camshaft they can get. So we've had to provide billet rocker arms to maintain stability in the valvetrain."

"There is only so much a stud-mounted rocker can take," agreed Eric Bolander of Howards Cams, Oshkosh, Wisconsin. "And with some of the newer heads—the valve lifts they require and the spring pressures they need to keep it safe—shaft mounts are the way to go."

Bill McGloghlon of PRW Industries, Inc. in Perris, California, added, "Reducing weight while maintaining rigidity is always a concern when designing rocker arms for racing conditions. That's why we design our rocker bodies using Finite Element Analysis (FEA), and manufacture them from the best alloys available."

Not surprisingly, the very same forces are driving innovation in valve springs. "The main trend continues to be lower mass and higher frequency," noted Billy Godbold of COMP Cams, Memphis, Tennessee. "This is definitely the case with our own new conical valve springs, but it is true of other new designs as

Considered among the most influential components in the valvetrain, rocker arms represent a constantly evolving category. And driving sales growth is advancing technology, along with a variety of new products designed to meet the demands of higher lifts, higher spring pressures, and higher rpm.

well. And with today's manufacturing processes and CNC equipment, we are able to manufacture higher-quality springs than ever before—even as the designs become more difficult to produce."

"Higher spring rates are still the trend as engine speeds continue to rise," added Jeff Villemure of PSI, New Hudson, Michigan. "Engine builders are consistently designing camshafts with higher lift as well, which drives up installed heights. This is generally the trend in all forms of racing. When selecting a spring, or designing a new one, we try to keep the outside diameter (OD) of the spring as small as possible. This allows the rate to increase with a minimal increase in mass."

At COMP Cams, said Godbold, "Often we are asked, 'How much spring do I need with that cam?' People misunderstand spring load as the primary factor in valvetrain control. That would be the case in a static system, but a valvetrain is extremely dynamic, with components operating closer to their resonant frequency than in any other part of the engine." Crankshafts and connecting rods, for example, might operate around one ten-thousandth (i.e. .0001x) their resonant frequency. "But we just can't do that with wire valve springs—and pushrods and rockers operate closer to resonance than most other components, too."

So it is best to think of the valvetrain as a system, Godbold added, "where the cam profile inputs certain dominant frequencies, and the valve springs must be able to control those frequencies without going into resonance. The trends toward smaller diameters and higher rates are both working toward higher-frequency springs, which allow [for] more aggressive camshafts and higher rpm limits."

We'll further explore rocker arms and valve springs, both separately and as a system, in the following pages.

Rocker Innovations

Rocker arms rank among the most influential components in the valvetrain, so let's begin with some specific new products, followed by a few notes on how these components are evolving.

Lavender Engine Development of Corinth, Mississippi, has developed a kit to convert traditional small block Chevy heads to LS-style pedestal rockers. "We created the system as a more stable alternative to stud-mount rockers for customers whose rules or budget does not allow a shaft-mount setup," explained John Lavender. "One customer reported a 12-horsepower gain on an engine dyno. Our

product costs less than guide plates or girdles, provides a 1.7:1 rocker ratio, and is legal in most classes that specify stock rocker arms." The kit does not include LS-style rocker arms, but it comes with all of the necessary stands, bolts, and shims "for simple installation in heads that are already machined for screw-in studs." The LS Rocker Conversion System is available exclusively through Howards Cams.

CHE Precision of Newbury Park, California, continues to offer a billet rocker stand .100-inch taller than a stock LS1 stand. "This enables the customer to use a longer valve-and-spring combination," explained Ed Doyle, "which in turn helps when they choose a higher-lift cam." Another continuing success for CHE has been its LS rocker arm retro-fit, where the factory needle bearings are removed and replaced with a bronze bushing and trunnion. "These work particularly well in off-road applications," Doyle added, "where dirt and debris can be a problem."

Modern manufacturing processes and refined CNC equipment now produce higher-quality springs, say our sources, who cited such current trends as lower mass and higher frequency, and purer material used in the springs themselves. Photo courtesy of Isky Racing Cams.

At the 2015 SEMA Show, PRW released "several stud-mount rocker kits manufactured from 2024 extruded aluminum for a wide variety of applications," said Bryce Kirk, "as well as a completely new, clean-sheet design made of 17-4 ph S3S stainless, and capable of withstanding higher spring pressures, while providing the consistent and stable valve events at high rpm that are critical to durability under racing conditions." Both new kits are part of PRW's Performance Quotient, or PQx line.

Titan Speed Engineering of Ojai, California, "recently changed the steel alloy we use to make our roller tips," reported Bob Sanders. "Heat-treating can always throw you some curves—and we always watch the feed stock, and where it comes from, like a hawk—but we are more than pleased with the new alloy and heat-treat combination.

"Also, we now have oil holes down through all of our adjusters," added Sanders. Titan makes ball-type adjusters in three lengths, and the cup type in one length, all using the 3/8-inch fine thread and 5/16 ball size.

Titan is working with Arias Industries to supply rockers for a new raised-cam version of Arias' Hemi Chevy where the camshaft is raised one inch.

Billet Rules

Experimentation, particularly at the high end of the market, is ongoing. And it continues to demonstrate that the total weight of a rocker arm is almost irrelevant, whereas the weight "over the nose"—that is, on top of the valve stem—could not be more critical.

When trying to control deflection in a rocker arm, noted Allan Bechtloff of Crane Cams, Daytona Beach, Florida, "you're moving into an area where the cost of the parts gets elevated. An aluminum rocker arm has mass and density, and that absorbs some energy, and at low rpm that's plenty good. But now you put in a heat-treated steel rocker arm, and it isn't bending or deflecting, and the motion designed into the camshaft is actually happening at the valve.

"It gets complex," Bechtloff mused. "Four grams can save you, or four grams can destroy you. We were trying to hit a bogey of 10,400 rpm for a Bonneville car. And we could get to 10,000, but then everything went crazy. And then we lightened the rockers by just four grams on the nose, and it wasn't crazy anymore."

"Increasing rigidity is always a concern," Sanders noted. "A very flexible rocker arm not only gives up some of the lobe lift, but can start a resonance that can add to valve float and lifter hammering. To address rigidity, we always stick with what works: Titan's arch and the sheer-wall design."

Design is not only critical, agreed Rob Remesi of Jesel in Lakewood, New Jersey, but is dictated by the material. "We've seen an increase in demand for steel rocker arms due to their added rigidity compared to aluminum. Unfortunately, we cannot always supply a steel equivalent to an aluminum-body rocker—and in most instances, you wouldn't want us to. If you were to take, say, an aluminum intake rocker for a spread-port, big block Chevrolet head, and make that same rocker out of steel, the weight of it would destroy the valvetrain harmonics."

Instead, the entire rocker-arm assembly must be re-engineered according to the weight and stiffness of the new material. "This is exactly what we did with the steel rocker kits that we've supplied for 410 sprint car engines," Remesi continued, "and with great success. We replaced an aluminum rocker body that was 1.600 inches wide with a steel rocker only .625-inch wide, greatly increasing strength while reducing the moment of inertia. Of course, that also meant taking the offset out of the intake rocker body, and instead rotating the individual rocker shaft to align the rocker with the intake valve and the offset pushrod."

Novak at Crower also reported tremendous success with steel billet. "We designed our billet rocker arms with the

help of some of the big engine builders," he said, "and then we took them to top teams, who tested them in their Spintrons to refine the weight over the nose, for optimum control of the valvetrain. It's taken us years to get to where we are now, but now we have such stability built into our billet rocker arms that the teams absolutely adore them, especially the dirt late model teams, who tell us that their valvetrain even stays adjusted longer, and that our billet rocker arms take the heat better.

"And now in some drag racing classes, especially in turbocharged applications, where they've been having problems with their exhaust rockers, they are starting to use our billet rockers on the exhaust side," added Novak.

Crower's billet rockers are forged in-house from 4340 chromoly; and they come with standard, needle-bearing, or bushed tips. The company also offers aluminum and cast stainless rockers, in shaft and stud-mount styles, for engine builders who prefer them.

Godbold suggested that engine builders should "take the time to measure system stiffness when changing rocker arms," and watch a few videos on using three-wire rotational pendulums to measure moment of inertia. Just understanding that you are now optimizing systems—and not just selecting good components—will put you way ahead of even where some NASCAR teams were a dozen years ago."

Godbold also confirmed that the market is changing, and that engine builders are "responding to favor stiffness, rather than looking at only ratio and mass. Most racers no longer use rockers with adjusters," as they realize that adjusters add not only mass but a potential failure point, while requiring the back of the rocker to be flattened out in a way that compromises stiffness. "Even the street market is turning away from them. The best shapes are arches or triangles with the tallest point high above the trunnion. Mounting systems and bearings are improving, too, all resulting in increased system stiffness. We now have customers who regularly change components and then measure the change in system deflection."

Still, Booth Platt of Proform in Warren, Michigan, reminded us of a more economical alternative. "Valvetrain rigidity is essential in a high-compression engine," he agreed, "because without it, energy is lost to flex, and susceptibility to failure is increased. To combat this there are two good solutions: a shaft-mount rocker system, or more affordable stud girdles, which interconnect all of the studs with rigid plates. The latter are easy to install, using the existing studs and not requiring any fancy machining. If you have room for roller rockers, you have room for a stud girdle. The most common limitation is having a tall enough valve cover."

The valvetrain should be thought of as a system, explained one industry expert, "where the cam profile inputs certain dominant frequencies, and the valve springs must be able to control those frequencies without going into resonance." In turn, he continued, higher-frequency springs "allow [for] more aggressive camshafts and higher rpm limits."

Lube & Roller Issues

While Phil R. Elliott of T&D Machine Products in Carson City, Nevada, stressed the importance of rigidity in these components, "it is not always the highest priority in every application. When it is the top priority, a steel rocker is the way to go. However, T&D continues to place more emphasis on all of the factors involved, to tailor our rockers for each specific application." Among those factors is lubrication; Elliott noted that T&D has always used pressurized internal oiling for its rocker tips and bearings.

PRW rockers, said McGloghlon, "are designed with oiling passages optimized for specific applications. Oil volume and pressure are taken into account when designing the lubrication system of each rocker arm kit."

With needle bearings, said Remesi, splash lubrication is sufficient. "Drilling through the center of a rocker arm to provide pressurized oil to the needle bearings does nothing but weaken the rocker arm. All of the rocker arms we manufacture for endurance racing, whether NASCAR or SCCA, rely on splash lubrication to the needles. We do believe in adding spring oilers to cool the valve springs, either through machining into the rocker stand, or by adding internal oilers."

"One of the biggest advantages of needle bearings," Bechtloff agreed, "is that they'll run on mist."

On the other hand, roller tips without needles do require some positive oil pressure. "Engine builders are trying to get as much oil as they can out of the engine," Novak commented. "Then they call us and say, 'Hey, I'm knocking the tips off of the rocker arms.' And we'll say, 'Are you restricting oil to the tip of the rocker arm?' And they answer, 'Yeah.' 'Well, that's why you're having those issues.'"

Godbold added a few words in favor of roller tips. "We know that at low speed and high lift, roller tips can reduce side loading on the valve. With high lift and high spring load, this results in less side deflection of the valve tip, especially in valves with very

small stems. With a 130-gram valve and a 1500-pound open load, you probably need a roller. As mass decreases and lubrication and surface finish improve, however, we do see more customers looking toward sliding-tip systems instead of rollers. They can be a good option when developed as part of a system solution where the valve mass and spring loads are strongly considered," he said.

Steve Slavik of Lunati in Olive Branch, Mississippi, observed that "the bigger the roller tip, the more contact area you have. But the main advantage of a full-roller rocker is the roller trunnion. The tip is secondary, and changing the tip can get pretty complicated." Lunati offers steel rockers with or without roller tips; "Voodoo" roller rockers manufactured from extruded aluminum; and LS-style cast steel rockers retro-fitted with roller trunnions. "We've made so many improvements over the past few years," he added, "that it's getting harder and harder to find additional refinements that would still be cost-effective."

Spring Collection

As a significant improvement to valve springs themselves, at least two manufacturers mentioned purer material.

"Valve spring wire continues to get cleaner," observed Nolan M. Jamora of Isky Racing Cams, Gardena, California. "Microscopic inclusions have become smaller and more homogeneously dispersed. This allows for higher maximum torsional stress, in turn allowing operation in higher stress ranges—that is, more rpm; and higher-velocity cam profiles with bigger rocker ratios producing a high rate of jerk along with more lift per degree."

"Since steel wears better than titanium, we're seeing an increased interest in steel retainers."

Isky has just released new additions to its Tool Room Super Rad valve spring lines, as well as a new Max-Life super-endurance series using a brand-new alloy steel, said Jamora, enhanced through "precision nitride heat-treating, and a multi-stage, micro-polished surface finish. Many hundreds of hours of Spintron testing has proven that these processes greatly enhance longevity in the most aggressive endurance racing applications."

Shaftech of Fostoria, Ohio, offers super-finishing of valve springs—while Nick Boes readily admits that the word "super-finishing" covers a lot of territory. "But our Omicron process is a non-chemical polishing method that produces an extremely fine surface on various materials. Specifically on valve springs, we

can reduce the friction between the inner and outer springs, while improving the spring's ability to shed oil. So the spring operates at a lower temperature, increasing fatigue life."

Meanwhile, PSI, Villemure added, "continues to advance our processing to maintain consistency from batch to batch. Customers need to have confidence that each set of springs they purchase will perform as well as the last set."

Bechtloff cited surface finish and lubrication as two of the greatest advances in recent years. "We're getting away with a lot of things we couldn't do before, because we are figuring out ways to make the parts super-smooth, and apply the lubricant only where it needs to be. You find a passage. You EDM a hole. You put in a squirter. You put the oil where it needs to be. We used to flood things with oil before we realized how much horsepower was lost driving that big oil pump."

Spring Fling

Beyond that, Bolander of Howards Cams commented, the springs haven't changed as much as "what we are asking them to do. As airflow improves in cylinder heads, more valve lift, longer valves, and taller installed heights become a necessity. And if the valve lift is .900 or 1.00 inch, the valvetrain must be sized accordingly. But that increased valve travel also increases the intensity of the valve spring harmonics. A valve spring does not travel on a rail, nor on a perfectly level foundation. As it cycles, even the best spring will bow side to side in the middle, sending harmonic waves through the whole spring. Those harmonic waves create heat, which can eventually lead to spring failure. So until we find a way to mount the valve springs on rails, and to prevent cylinder heads from expanding and contracting with temperature, the best we can do is to keep spring rates as high as practical, in order to reduce harmonics."

Increasing wire diameter to increase the spring rate "was certainly the favorite option, back in the day," Bolander continued. "Bigger wires equated to more pressure and a better harmonic absorption. But as the runner sizes in cylinder heads have increased, so has the need for smaller-diameter valve springs. And as the diameter of valve springs decreases, so does the distance between 'running great!' and 'catastrophic failure.' So materials, geometry and setup all become more critical. Without overstating the obvious, as spring rates, spring pressures and rpm's go up, so does the need for stronger and better-fitting valvetrain parts. Make sure your retainers fit the springs tightly, that your locks seat well in the retainer, etc. Close enough is no longer good enough."

"Installed heights are trending higher," Godbold confirmed, "to keep the OD and resulting coil mass down. Smaller-OD

springs are lighter, but you cannot achieve high lift with them without allowing room for the spring wire to move. It can only go up or out. We are seeing this not only in NHRA Pro Stock, but also in the new Voodoo head for the 5.2-liter Ford (with approximately 0.200 inch more installed height than in a base Coyote); and we saw it when GM increased the installed height by 0.100 inch in the LS7, LT1, and LT4, relative to the older LS1 and LS3. Chrysler took the same direction when they developed the Apache head from the earlier Hemi. Regardless of whether it's on the track or on the street, adding installed height provides more room for the spring wire without increasing OD and lowering the frequency.

"Now we are also starting to see a trend toward rethinking older designs using a smaller OD to obtain the same or lower spring rate. If you can get the spring mass down, you can reduce higher frequencies without going to higher rates," he said.

Jamora added that higher spring rates can be achieved either through increasing the cross-section of the wire or by decreasing the overall diameter of the spring. "Each route has advantages," he said. "The former reduces stress and increases longevity. The latter reduces mass; however peak stresses increase, and with them the tendency toward stress-induced failure."

In general, Novak sees the market moving increasingly toward custom-engineered, application-specific springs. "Everyone is different. We're constantly purchasing new valve springs to fit new applications," he added.

Supertech Performance of San Jose, California, "concentrates on the sport compact market," said Willy Tagliavini, "where especially in drag racing the quest for more power is never-ending." One popular practice to gain more power is to install a radical camshaft, increasing both valve lift and duration—and therefore requiring valve springs that can provide both a longer travel and higher pressure. "This is achieved mostly through higher-grade materials, heat-treatments, surface treatments, and larger-diameter wire—and if possible, increased installed height."

Turbocharging is also popular, and "more boost pressure requires more spring pressure, especially seat pressure," Tagliavini explained. "Usually in these cases lift is not very high, but the required pressures can still be difficult to achieve within the physical constraints of the cylinder head.

"Our titanium retainers can withstand fairly high spring pressures, but in some cases we need to increase the contact area between the retainer and lock, to prevent the retainer from pulling through the lock—although this only happens in very aggressive drag race applications.

When it comes to rocker arms, design is often dictated by the material, noted one of our contacts. "We've seen an increase in demand for steel rocker arms due to their added rigidity compared to aluminum," he said, but added that it isn't always feasible to produce a steel equivalent to an aluminum-body rocker.

Still, since steel wears better than titanium, we're seeing an increased interest in steel retainers," he concluded.

Keeping Up the Pressure

No matter how strong a spring may be when it's new, metal fatigue eventually robs it of both spring rate and other characteristics. "Spring fatigue can lead to reduced performance," Platt noted, "and the very best way to test for this is with a valve spring tester." Proform offers "a wide variety of valve spring testers for just about every budget, ranging from 'mini testers' that are used in a regular shop vise, up to thousand-pound digital bench-top testers offering one-pound resolution. We even have units you can use right at the track." Proform provides spring compressors as well, to free valve springs from their keepers and remove them from the cylinder head. He asked, "Have you checked your valve springs lately?"

And while you're checking, Bolander offered some specific numbers. "The minimum safe spring pressures for a solid roller camshaft are 100 pounds per .100-inch lift; that is, a .700-inch lift needs a minimum of 700 pounds open pressure. And, within reason, more pressure is always better." Within reason means that you do not "need a 1300-pound-open-pressure triple spring for your .600-lift circle-track application. You want a spring that is heavy enough to not let the lifter loft off of the nose of the cam, and to close the valve with authority; but not so heavy that it will generate excessive amounts of heat."

Jamora recommended running a spring damper whenever possible. "A properly designed damper-spring will give you a full spectrum of rpm with control of resonant vibration—especially important in today's endurance racing." He also pointed out yet another reason to use a racing oil containing "a generous percentage (i.e. 1550–1600 ppm) of the zinc-based anti-wear additive ZDDP.

Kirk cited yet another issue, this one resulting from "consumers not realizing that when you change your rocker arms, or mill your head, you need to change the length of your pushrods as well to maintain proper valvetrain geometry." PRI