BELOW In all categories, particularly those where the basic design of the engine is constrained, competitors are increasingly seeking an edge through the reduction of losses

NEW FRONTIERS

Chris Pickering enlists the help of experts to tackle some preconceptions about the bottom end of the engine, plus look at recent developments in the market

TRYING to cover even a tiny amount of what's happening in engine technology in these few pages wasn't going to be easy. The clue is in the name after all ... motorsport wouldn't be much without the motors. So what we've done is to come up with a cunning plan, which involves chopping the engine into two halves. In this first report we're looking at the bottom end of the engine, the cylinder block and the reciprocating assembly.

It's an area which is often thought to be largely about strength. There's a misconception that while the combustion chambers and the breathing systems do all the glamorous power-producing work, the structural components beneath simply slog away, doing their best to hold together at however-many thousand rpm. Of course, that's no mean feat in itself, but there is far more to it. Weight, for example, plays a major part as engine designers continue to shave precious grams from the rotating and reciprocating assemblies to improve response. Similarly, friction reduction is one of the great new frontiers in motorsport. In all formulas, but particularly those where the basic design of the engine is quite heavily constrained, it gives a vital area where losses can be reduced, and power gained.

Total Seal

It's easy to underestimate the importance of piston rings. On first glance, a tiny slither of metal barely a millimetre in thickness might not appear that significant. But these little pieces can have a big impact. Friction, durability and reciprocating mass are all influenced by piston ring design, and it's an area that's been advancing rapidly over the past few years.

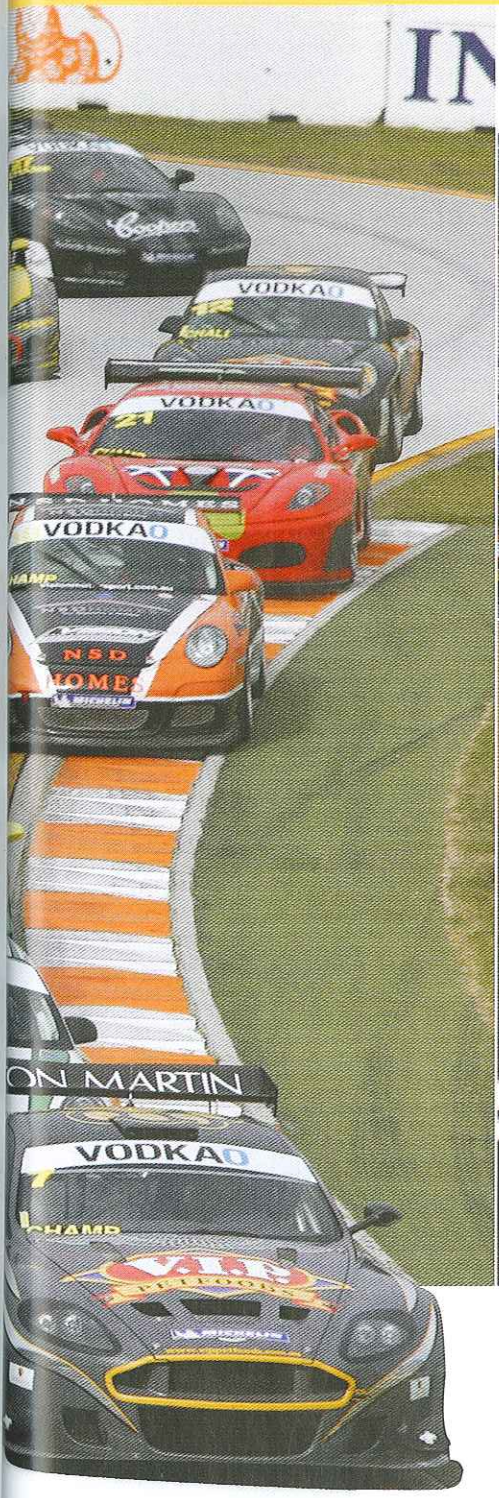
Total Seal, based in Phoenix, Arizona, has been working in the field for many years and supplies to virtually all disciplines of motorsport. Recently it has focused on developing the smallest and lightest rings on the market, explains Total Seal's Ed Law: "The days of a 0.043" or even a 1.0 mm ring in professional racing are quickly going by the wayside. Today's customers are requesting rings that are 0.8 mm and thinner. Most top level teams use rings between 0.6 mm (0.0236") and 0.7 mm (0.0276") axial thickness."

There are several advantages of using these ultra-thin rings. The first benefit is the reduction in mass. "A 0.043 in x 0.155 in top ring weighs 9.5 grams. Our typical 0.7 mm top ring weighs 4.7 grams," Law states. "This is a 50 per cent reduction in ring mass. If you continue down to the 0.6 mm ring, the mass drops to 3.8 grams." And with this reduction, he points out, comes a direct effect on the acceleration rate of the engine.

Another advantage is the increased conformability of the rings. As the rings become thinner, both axially and radially, they will conform to the cylinder wall better. This, Law claims, translates into increased ring sealing and improved volumetric efficiency. Similarly, by manufacturing in smaller cross sections it's possible to lower the tangential tension of the ring pack, which, in turn, reduces the friction.

"Here is a good comparison of two ring packs," says Law. "A typical 0.043 in 0.043 in 3.0 mm ring pack has a mass of 29.2 grams and has a tangential tension of 15 lbf per cylinder. Total Seal's 0.7 mm, 0.7 mm, 2.0 mm package has a mass of 16.8 grams and a tangential tension of 8.2 lbf. As you can see, this thinner package reduces both the mass and friction by approximately 50 per cent."

The finish on the rings is also extremely important. Total Seal claims its Diamond Finish Ring line has the tightest tolerances



LEFT Total Seal's production line in Phoenix, Arizona

BELOW Those tiny slithers of metal might not appear too significant, but piston ring technology can have a big impact on performance

and the smoothest and flattest finish in the industry. This, the company claims, is essential when sealing the ring to the ring groove, and helps to eliminate a critical leak path.

Coatings on the piston rings are also rapidly advancing. Coefficient of friction is always considered when choosing a coating, but this is not actually the driving force in face coatings. According to Law, the primary consideration when choosing a coating should be the compatibility with the bore or bore coating. And these days, with many new bore coatings coming onto the market, this adds an extra dimension to the task. "Nickel Silicon Carbide has been around for many years, but the new plasma coatings are taking a stronghold," he says. "With that in mind, we're working very close with Sulzer Metco to develop rings that are compatible with its new bore coatings, such as 30 per cent moly, 50 per cent moly, and titanium dioxide."

Quality control is an important part of the process too. "We now have the ability to inspect the OD face of the ring at a resolution that was almost unheard of a few years ago," says Law. "One of the inspection capabilities we have is to look at the shape of the face of the ring. If you take a 0.7 mm thick ring (700 microns), we can analyze the face at a resolution of half a micron. This means we look at 1,400 points across the face." This level of resolution becomes imperative when customers are demanding face profiles that have +/- 2 microns on the barrel drop and +/- 20 microns on the tangent point of the barrel, he explains.

Capricorn

Capricorn Automotive is a familiar name in the world of motorsport reciprocating assemblies. For years the company has been one of the key players in bore liners, honing techniques and piston manufacture, but now it's diversifying into the field of hard anodising.

Hard anodising is, as the name implies, an electrolytic process that forms a hard oxide layer on a metallic component. The company's process uses a well recognised system of cleaning, rinsing, and sulphuric acid treatment, but it is the attention to detail that is key in this market in order to ▶

BELOW Capricorn has the in-house ability to perform all of the processes linked to high performance pistons

achieve the sub-5µm size and flatness tolerances demanded by customers at this end of the spectrum; Capricorn deals extensively with many motorsport companies as well as motor manufacturers and individuals.

Much consideration was given to ensuring that only the best quality cooling and electrical plant was employed in order to achieve a consistently high-quality end product. Meanwhile, a lot of development work was carried out in order to achieve an effective and repeatable masking solution, as it is imperative that the anodising treatment is only applied to the desired area.

"We are pleased with successful implementation of this new process into our Basingstoke site," Capricorn MD Martin Keswick comments. "This rounds off our in-house ability to do all of the processes linked to today's high performance pistons, including forging, profile pin boring, skirt coating and now hard anodising."

CP-Carrillo

Increasingly we're seeing companies that can offer not just individual components, but a complete reciprocating assembly. One such concern is CP-Carrillo, the product of a recent union between piston specialist CP and renowned conrod manufacturer Carrillo.

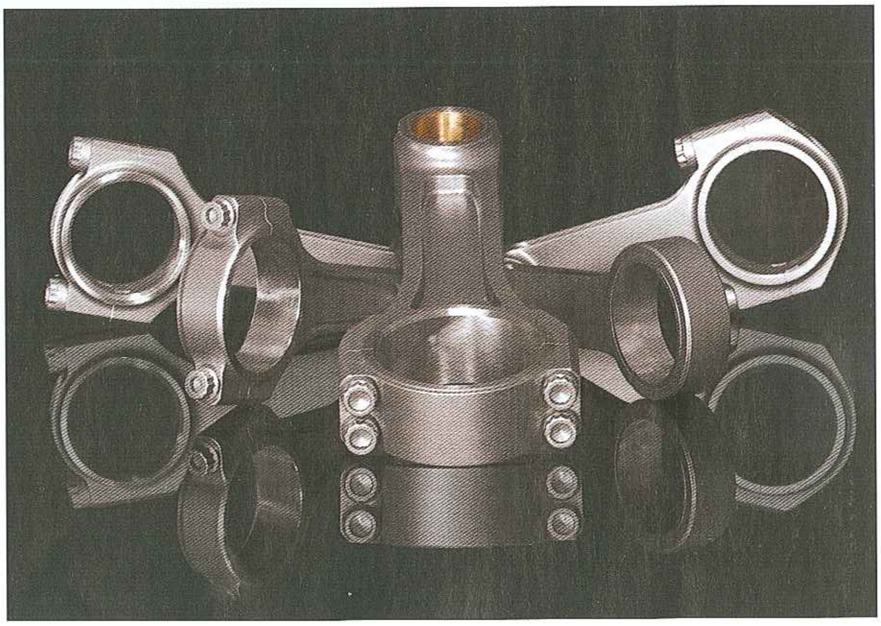
On the conrod side, the company's engineers have been making extensive use of FEA simulation to refine their designs. The latest offerings use smaller wrist pins, reduce peak contact stress and improve the stress distribution. This is said to improve the longevity of the bushing, as well as lowering the reciprocating weight. The FEA studies have also allowed the company to develop its big end designs, with improved bearing load distribution and a claimed reduction in big end bore distortion under load.

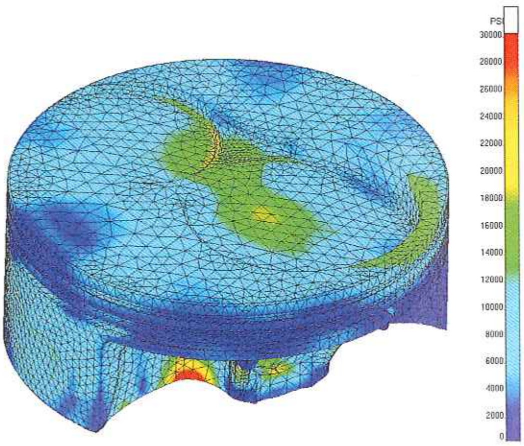
The manufacturing processes have also come under scrutiny. "We've increased the number of forgings on hand and updated the heat treat specifications," explains CP-Carrillo engineer Stefan Penz. "The updated heat treat specification introduces less stress into the part when quenching, which helps to improve its strength. And we also offer ASF treated rods. Besides the obvious shine, the ASF smoothes the surface, reducing the possibility of crack initiation points, and also aids in shedding oil. What's more, the thrust faces are lapped to reduce friction and wear on all our double-guided applications."

The company has also begun looking at aluminium connecting rods, in addition to the usual steel items. Initially the focus will mainly be on drag racing's Top Fuel and Alcohol markets. The new aluminium rods feature an improved cap design that smoothes the transitions to reduce stress concentrations around the bolt heads.

Things have also been busy on the piston side of the business. "One of the things we've focused on over the last year or two is reducing friction in the cylinder, while still maintaining piston stability," comments Penz. Eccentric skirt shapes, ellipses and cam shapes have been developed to reduce the amount of piston movement at high rpm.

"With these reduced harmonics in the bore, it allows the rings to do their job in a superior fashion by sealing off the cylinder better than our competition," he continues. "To go a step further, we have also ▶





ABOVE & LEFT CP-Carrillo's engineers have made extensive use of FEA simulation to refine the design of their conrods (above) and pistons incorporated ways to decrease pressure between the top and second ring, enhancing top ring sealing while ensuring oil stays in the crank case."

Balancing a piston by controlling the location of its centre of mass is another aspect the company has been looking at, as a means of allowing tighter piston-to-head clearances. "This is often easier with a billet piston, but is also done with some of our forged designs," notes Penz. "Some of the more recent piston designs have taken into consideration the diversity of any given market and allow us to incorporate advanced 5-axis machining on the underside of the piston to yield a balanced part."

The structure of the piston is key to making sure the wristpin bores are not compromised, he explains. By developing braces, struts and ribs in certain thicknesses and angularity, the engineers hope to boost rigidity in the pin bosses, which creates a more solid foundation for the wristpin. The design of the pin itself, along with the structure of the piston and the rod design as a package, enables Penz and his colleagues to optimise the whole assembly through FEA, helping to produce components which are both lighter and stronger.

BELOW Pankl is one of the main players in the trend towards supplying whole reciprocating assemblies

Pankl Engine Systems GmbH & Co KG

Pankl Engine Systems is another well-established in the field. The Austrian firm has specialised in the development and production of reciprocating components and assemblies since 1985. So how does the market differ today? "Generally the regulating bodies are trying to bring motorsports technologies closer to OEM relevance," explains Pankl's Christoph Wachmann. "These trends include the use of downsizing strategies, such as turbocharging and direct injection, which increase the technological demands placed on crank mechanisms. At the same time, there is a strong desire to reduce costs and increase longevity."

With these trends come new challenges, however. The continuing rise of diesel technology in motorsport and the move towards downsized petrol engines has seen cylinder pressures go through the roof. This has had a knock-on effect on the load the components are subjected to, which has put even greater emphasis on material choice. Fundamental properties such as Young's modulus, thermal conductivity and fatigue characteristics are key, as are the design and simulation techniques used, as well as manufacturing considerations such as machining processes and coating types.

Achieving longevity requires a careful balance too. "You can't increase the lifetime of the engine by simply making the components more substantial," Wachmann explains. "A heavier piston and piston pin, for example, may reduce the life of connecting rods, bearings and crankshaft."

Pankl's response to this is constant improvements to the design, machining and coating processes. Recently it has begun to include elasto-hydrodynamic (or EHD) calculations to its FEA simulations. This enables the Pankl engineers to model the lubrication of bearing surfaces on the pistons, con rods and crankshafts. All the simulations are run with nonlinear material characteristics, appropriate temperature representation and explicit modelling of the boundary conditions.

The other end of the development process is physical testing. Pankl uses pulsed tests of connecting rods, bolts and piston pins, performed under realistic load and temperature conditions to evaluate its new materials and designs. In order to take care of any dynamic phenomena two engine test benches (V2 and single cylinder) are installed at the company's facility to further increase the maturity of new products and designs before approaching the market. All the physical testing results are then fed back into the development process and used to refine the end product.

Materials play a major part in this ▶

process. "We are continuously developing materials and heat treatments," comments Wachmann. "As the market steadily requires higher lifetimes of lighter products being used under higher loadings, the importance of coatings and surface treatments grows more and more." This includes coatings to prevent wear, heat damage, excessive friction and the dependence on external lubricants.

Once the initial tests have been conducted Pankl's metallurgists can examine the materials for any potential areas of improvement. Tools such as scanning electron microscopes, spectrometers and hardness test devices are all employed in the optimisation.

The company was also one of the main drivers in the current trend towards supplying whole reciprocating assemblies. "Today a significant portion of Pankl rods are already fitted with Pankl Pistons," says Wachmann. "We expect this number to rise significantly, as more and more customers see the benefit of giving this responsibility to a specialist and keep concentrating on their core competencies such as CFD and cylinder head design with their limited resources."

Callies Performance Products

According to Duane Boes of Callies Performance Products, there are three main areas in which conrod technology has advanced over the past few years: material characteristics, precision threading and big end design.

"Today's metallurgy has created a never before seen balance between high hardness and high ductility," he comments on the first subject. "These materials allow hardness levels over 50 HRc to be attained, despite maintaining over 12% elongation and a 45% reduction in area. These characteristics combined with an ultimate tensile strength over 280 (KSI) result in a housing bore with little deflection under load."

> "Today's metallurgy has created a never before seen balance between high hardness and high ductility"

Next comes precision threading. Current internal thread milling technology allows extremely clean and precise threads to be cut into very hard material, he explains: "Threads generated through milling are very clean, having true form, no surface tearing and excellent finish. These thread characteristics are a benefit to clamping consistency and they allow you to cut into materials that would have been simply too hard a few years ago."

Finally we come to the seemingly minor changes in material distribution around the big end bearing housing bore that Boes maintains can yield significant improvements in bore stability. "The areas of concern are at 5, 7, 10 and 2 o'clock," he notes. "With today's focus on minimizing rod and main journal oil clearance, the ability of a rod to maintain roundness under load is very important."

The pace of evolution has been somewhat slower on the crankshaft side, he argues, but there are still benefits to be had. Again, ▶

BELOW Conrod technology has advanced in terms of material characteristics, precision threading and big end design manufacturing techniques play a major part. "Geometry is improving as manufacturing technology continues to become more precise," he says. "Journal roundness is now at never before seen levels of consistency. It has become common place to measure journal characteristics in micron resolution."

Surface finish throughout the shaft has become an area of focus as well. Understanding that Rv (Maximum Valley depth) can have significant influence on endurance, a strenuous effort is being placed on producing highly refined finishes on journal fillet radii.

"To validate these endurance improvements, we have set up a comprehensive crankshaft fatigue testing laboratory," reveals Boes. "We are able to evaluate shaft characteristics for both bending and torsional type loads. We believe we're the first performance crankshaft manufacturer to invest in this capability, and we are presently testing diesel crankshafts in addition to our own products."

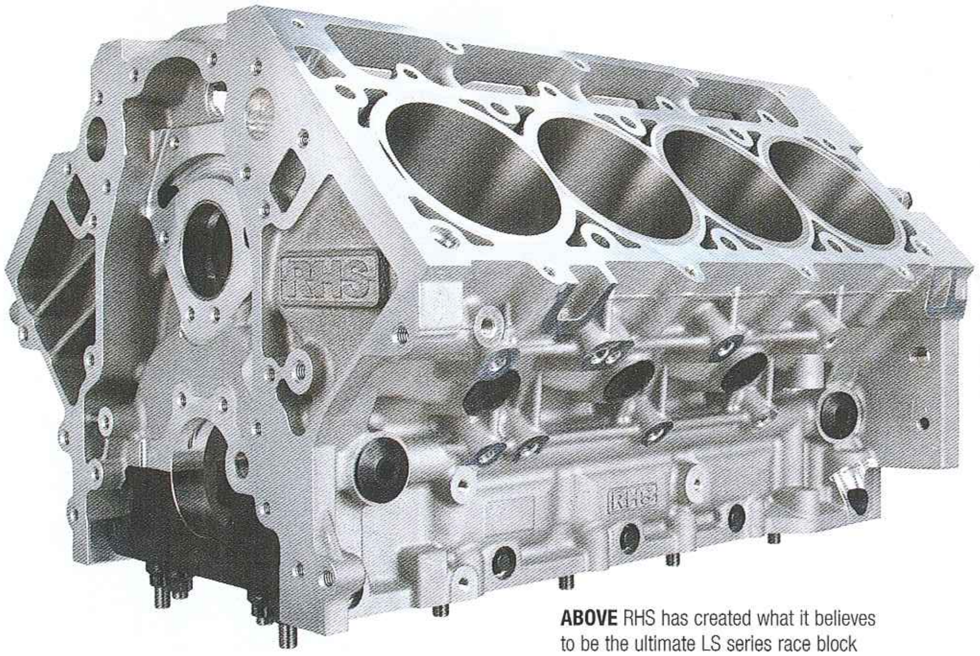
The search for greater durability has also led to the company super-finishing the entire surface area of its crankshafts – a practice which has been common in F1 for some time, but one that's only just starting to trickle into other high performance applications.

RHS

The Chevrolet LS series has long been one of the mainstays of the engine building industry – particularly in the US, but increasingly in Europe too. And it was with this in mind that Racing Head Services – better known as RHS – set about creating what it believes to be the ultimate LS series race block. It comes in both standard and tall deck heights, with a 4.6 inch stroke as standard and a range of bores in 4.060 to 4.165 inch diameter.

The blocks are manufactured from high-strength A357-T6 aluminium, that's hardened in a unique solidification and cooling process. Its design features increased bay-to-bay area for improved breathing, as well as a raised camshaft centreline position (in the block in the case of the pushrod-equipped LS) and a dry sump-ready lubrication system (along with wet sump provisions).

The LS tag is almost slightly misleading. Far from being a lightly fettled version of the production unit, it is in fact a heavily re-worked design cast from scratch by RHS. It features Siamese cast bore walls with pressed-in spun cast iron liners and an improved cooling system based around the LS7 water jacket. A six-bolt head stud arrangement, taken from the LSX engine, provides extra strength, as do chilled main bearing bulkheads and rolled threads on all threaded holes.



ABOVE RHS has created what it believes to be the ultimate LS series race block

"We ploughed over a year of heavy R&D into this project," comments Brian Reese, vice president of engineering for the COMP Performance Group which owns RHS. "We spared no expense in an attempt to create the ultimate LS race block, but it hasn't been easy. It's an extremely complicated casting and we worked hand-in-hand with a specialist foundry to achieve it."

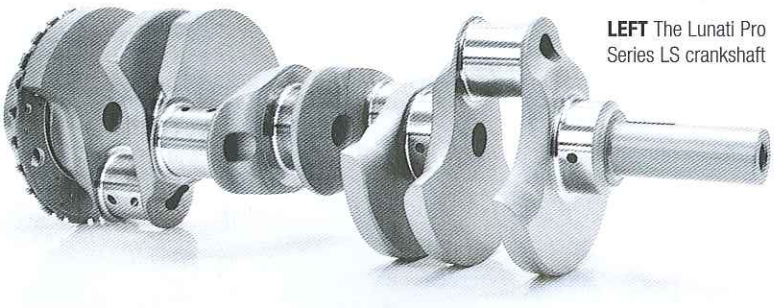
Lunati

Lunati has been supplying engine components to the US racing scene since the 1960s. Company founder Joe Lunati began by supplying camshafts to weekend drag racers, before expanding into the crankshaft market. These days the company can go one step further – specifying and supplying a complete reciprocating assembly. The kits comprise of a crankshaft and connecting rods from the company's own range, matched to ARP rod bolts and Wiseco pistons, pins, rings and bearings.

So what does the company set out to achieve with these kits? "Top of mind is the need for a strong, reliable crankshaft," explains Lunati general manager Derek Scott. "Beyond that, people still want more capacity. As they say, 'There's no substitute for cubic inches', and we're always looking for a longer stroke."

Scott is very proud of the company's new LS7 and LS9 crankshafts, which are available in a range of strokes and pin sizes. "Our long snout crankshafts use 4340 steel forgings and meet aircraft quality standards for material cleanliness and purity," he says. The Signature Series Crankshafts have been successfully used in 1,500+ hp drag racing applications, we're told, and the company also has a range of recently revised cranks for supercharged small block Chevy applications.

On the conrod side, each example is forged from high quality 4340 alloy steel for strength and utilises Lunati/ARP rod bolts, designed to produce superior clamping force on the rod journal. "The rods endure some of the highest stresses in an engine's bottom end, exceeding 12,000 lbs in race applications so we ensure no corners are cut in the manufacturing process," notes Scott. RT



LEFT The Lunati Pro Series LS crankshaft