

Pistons have come a long way in recent years. Here, Federal-Mogul's high-tech EcoTough coating is being applied to a gasoline piston

Pumped up

Its function might be relatively straightforward, mechanically speaking, but the humble piston is far from simple. And as engine sophistication continues to increase, so too does the complexity of the modern piston

WORDS: MATT ROSS

Nowadays, engines tend to be hotter, smaller and boosted. So how do today's modern pistons compare with their older counterparts? And perhaps more pressing, what does tomorrow hold for this vital engine technology?

"In the past 20 years, engines have undergone big changes – much greater than those seen in preceding decades," says James Allen, head of design at Cosworth. "Earlier pistons were used primarily in normally aspirated engines, and their design was based very much on experience and previous designs. Modern engines are more likely to be boosted, with higher specific power output. This places much greater demands on the piston."

And those demands need to be met on a multitude of fronts. For piston developers, focusing on any one single area of research – be it component design, material selection, manufacturing processes or friction reduction – simply won't cut it. So tight is the link between these factors – change one and you invariably affect another – that research and development into new piston technologies has thrown up a mass of challenges and solutions.

Downward trend

Downsizing has rendered the operating conditions in modern engines far more intense. "Piston design is a greater challenge because of the increased performance, and the increased peak fire pressure you now have in the combustion system," states Jens Wartha, diesel powertrain engineer at GM. "Basically you have to design the piston in a way that means it will survive."

Hotter, higher-pressure boosted engines are a hostile place for pistons, and component developers are striving to stay ahead of that curve in terms of composition, design and friction reduction. "Piston materials have had to evolve, as has the design of the piston, to ensure adequate fatigue performance due to increasing load demands," explains Sebastian Howell-Smith, technical director of Capricorn Automotive.

"Changing lubricant rheology places increased demands on combating unwanted frictional asperity interactions, requiring greatly increased attention to tribological issues for the piston-cylinder system as a whole."

Managing thermal performance is equally vital, and requires the latest design and inspection techniques to develop specialist cooling geometries. "We have to manage the heat flow path from the piston crown to the ring pack by methods such as internal cooling galleries," adds Federal-Mogul's director of technology, global pistons, Frank Dörnenburg.

"Thanks to our in-house developments in 2D ultrasonic inspection, we can ensure robust series production even with the gallery positioned high in the crown, where it is most effective. This would not have been practical a few years ago. We have also developed new materials to withstand the increased temperatures, as well as strategic techniques such as Durabowl, which re-melts the material around the combustion bowl ring on a diesel piston to increase the fatigue strength."

"Piston design is a greater challenge because of the increased performance"

Jens Wartha, diesel powertrain engineer, GM

1. Capricorn Automotive's facilities in Basingstoke, UK. The company offers specialist piston design, analysis and manufacture



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Embracing efficiency

The race to produce engines that are increasingly efficient, and capable of meeting stringent emissions targets, also has consequences for piston design. "For us, higher efficiency means lower mass pistons operating at higher temperatures, higher ignition pressure and lower skirt friction," outlines Arnd Baberg, chief engineer, product engineering at Federal-Mogul. "We operate the piston material closer to its temperature limits and improve the thermal management by using a cooling gallery high in the piston, behind the ring pack, or an Alfin insert to carry the top ring. In gasoline applications, both methods mean greater robustness against knocking, so our OEM customers can use higher compression ratios, or calibrate combustion across a wider crank angle range. These technologies are applicable to both gasoline and diesel pistons because developments such as downsizing, turbocharging and DI have become widespread in both."

Meanwhile Howell-Smith at Capricorn says that friction reduction is the key driver when it comes to reducing piston-bore parasitic losses. "Increasing in-cylinder loads and evolving crown geometry place additional thermo-mechanical loads on pistons – in local regions and overall. These require a matching progression in terms of design, materials, coatings and processes employed."

On the whole, it seems that there's no one single approach to developing new pistons for modern engines.



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2. A recently developed AVL piston. The supplier believes pistons will be a fundamental part of vehicle powertrain development for many years to come

The solutions are as varied – and also as interconnected – as the challenges. For Federal-Mogul, a multidisciplinary approach is clearly important: "Key milestones have been the introduction of new, high-performance aluminum alloys and coatings, Durabowl, raised cooling galleries and advanced non-destructive testing techniques," says Dörnenburg. "All of these have improved piston durability, despite the gradual increase in engine power output and combustion pressures. Technologies such as cooling galleries and top ring land inserts have migrated from diesel to gasoline applications as the firing pressures in today's high-output gasoline engines match those of the diesel engines we had 15 years ago."

The possibility of implementing steel pistons in passenger vehicles is one that has begun to garner interest. A number of leading suppliers (and several OEMs) have been conducting research into whether steel – which boasts a higher yield strength than aluminum, and can offer a potentially lower piston height but has lower thermal conductivity and requires greater cooling – is a viable material for pistons in diesel-powered passenger vehicles.

ELECTRIC DREAMS

By their nature, electric powertrains don't use pistons. So is the EV movement giving piston developers sleepless nights?

The simple answer is 'no'. "If you look at the current market introduction, and the future market introduction, we currently see a very low percentage of vehicles without a combustion engine," says Wolfgang Schöffmann, AVL's head of design for passenger car powertrains. "If we look toward 2025, we will see the majority of vehicles still with piston engines, coupled with electrification of some kind. I wouldn't be concerned that we will have piston-less engines."

"We've got a long, long way to go on IC engines with pistons," says Ford's Joe Bakaj. "I think the market will move more toward hybrids and plug-in hybrids as

we get to 2020 and 2021, and of course both these electrified products still rely on the IC engine. The pure EV market share is still a very low percentage."

And even if an unexpectedly sudden demand for electric powertrains caused consumers to flock to pure EVs in substantial numbers, the days of the piston don't appear to be numbered. "In the medium term, we anticipate that any reduction in sales volume due to the growing EV market share, or downsizing trends toward engines with fewer cylinders, will be more than offset by the huge increase in demand from emerging markets," says Federal-Mogul's Dörnenburg. "Our projections, to at least 2020, are for continued growth in piston manufacturing volumes."



"In the diesel field, the latest technology that everybody is working on, us included, is steel pistons," reveals Joe Bakaj, vice president of product development at Ford. "We don't produce our own pistons anymore; we work with the big piston suppliers. But we are also doing a lot of in-house work to understand where the opportunities are, and the potential benefits of competing technologies."

Federal-Mogul's Baberg agrees with his Ford counterpart: "The prospects for steel pistons are exciting and they could be of interest for smaller engines if exceptionally high temperatures and loads are to be contained. Steel pistons have started to penetrate the passenger car diesel segment, and our OEM customers will determine how far this trend progresses."

It's no coincidence, then, that in January 2015, Mahle announced that it would be manufacturing steel Monotherm pistons for Renault's 1.5- and 1.6-liter four-cylinder diesel engines, the first instance of such pistons entering series production for a diesel passenger car.

Key analysis

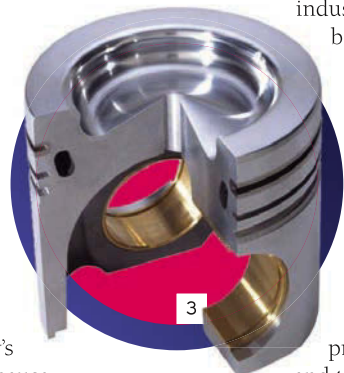
Advances in component design, materials and friction reduction are all vital to the development of new pistons. But OEMs and suppliers alike are also pursuing advances in the simulation and analysis of new designs. "The improvement in modeling capability of the piston over the past 10 years has been tremendous," says Ford's Bakaj. "Capability under dynamic conditions has always been the issue with pistons, but that's improved quite dramatically."

Federal-Mogul's Baberg further explains where the industry is at: "Today's pistons are more highly optimized because the analysis of temperature, deflection, stress and fatigue life is more accurate now, and also quicker to execute. This has helped in achieving lower piston weights."

"Analysis is the tool that enables better piston design through greater understanding. New materials, treatments and process developments then allow the hardware to be delivered robustly in series production."

Capricorn's Howell-Smith fully agrees with Baberg's outlook: "A notable addition is multiscale testing to

1. Federal-Mogul Monosteel diesel pistons are manufactured by friction-welding the crown to the skirt, creating a large volume cooling gallery between the ring pack and the combustion bowl



increase knowledge about the ever-changing boundary conditions within the cylinder system," he says. "Higher accuracy boundary data is essential to formulate a current representative model of the cylinder system, thereby allowing a cyclical, prioritized and measured approach to development."

Predictions for the future of the piston, from industry developers at least, are largely evolutionary based, all of which suggests that the piston of 2020 will look pretty familiar. Though the rise of alternative drivetrain technologies is noteworthy, the majority of suppliers believe that pistons will continue to be in common use, with designs not radically different from those of today. "The gasoline pistons of 2020 are more likely to make greater use of reinforced inserts and cooling galleries," predicts Dörnenburg. "Diesel pistons are more likely to use a premium aluminum alloy material, or steel, and to be a little smaller in diameter than today."

Cosworth's Allen also agrees that it's far more a case of evolution than revolution: "We have explored radical piston concepts, such as metal matrix composites, in racing applications and others that can justify the cost. A big reduction in the cost of one of these technologies could affect piston design considerably, but we don't believe that we are yet at the limit of more conventional techniques. The piston of 2020 will most probably be an evolution of current designs." ◻

2. EcoTough coating cuts piston-to-bore friction by up to 13% in diesel applications and 10% in gasoline over the best coatings that were previously available

3. By using a cooling gallery high in the piston, Federal-Mogul pistons can operate reliably at higher combustion temperatures and under higher pressures

4. Mahle steel pistons for passenger car applications. The company recently announced that Renault's 1.5-liter and 1.6-liter four-cylinder diesel engines would be using Monotherm steel pistons

