# Burning ambition

**As fuel costs continue to rise and the Euro 6 emissions regulations draw ever nearer, injection system and engine designers are rising to the challenge. Brian Tinham reports**

Right: heavy-duty diesel engines on test at Ricardo

Amongst the most obvious developments on heavy-duty diesel engines in recent years has been the emergence of common rail diesel injection systems, bringing all the benefits long since accepted in the automotive sector, but with way higher numbers. Injection pressures openly discussed today are in the 2,500 bar region for trucks and some even talk of 3,000 bar. Each of the main system developers (independents and truck OEMs) is also claiming multiple injection capabilities, with most citing at least five injections per cycle and some many more – all under software control.

Fundamentally, common rail offers the advantage of separating the former dependence of injection pressure on cam timing and hence engine revs – so significantly improving engine performance in the lower range. But that's not all: behind the scenes, a mix of technologies is being brought to bear to meet the dictates of the Euro 6 emissions regulations, without pricing trucking out of the market.

**Comon rail compression**

Chris Such, chief engineer at Ricardo, responsible for heavy-duty engine development at the firm's Shoreham Technical Centre, agrees that common rail is one of the critical enablers, citing Bosch, Delphi and Denso as leading developers.

"Benefits from common rail include faster heat release inside the cylinder. That comes from the higher pressure, fine spray of fuel injected through smaller, tighter tolerance nozzles, which also results in extremely low soot emissions," explains Such. "In turn, this has the advantage of lower soot loading on the downstream DPF [diesel particulate filter],

meaning potentially a smaller, lighter unit, while also reducing the energy required for regeneration. There's still some way to go on this and we're currently exploring some of the options."

And there's more: "You can also gain the benefit of very precise fuel metering, so the system only pumps to match the engine ECU demand, rather than recirculating fuel back to the low pressure side," explains Andy Noble, Ricardo's project director for heavy-duty engines. "That means energy losses don't rise in line with pressure, but arguably fall, certainly compared to the hundreds of thousands of trucks running early common rail systems."

### Catalyst efficiency

It's a similar story with SCR (selective catalytic reduction) after-treatment systems, with the most notable improvements coming in the form of increased catalyst efficiencies, not least through improvements in precise exhaust temperature management. That development is best illustrated by Iveco's recent unveiling (with FPT Industrial (Transport Engineer, July 2011)) of the first Euro 6

compliant engines without the hitherto essential EGR (exhaust gas recirculation) pathway.

"Iveco appears to have achieved an SCR efficiency of 96% over the test cycle, which is remarkable," comments Such. And he adds: "With that capability, there is also scope for the combustion system to be optimised for lower $CO_2$ emissions, which means reduced fuel consumption."

Iveco is not alone in improving the effectiveness of SCR, at least in part by focusing on exhaust temperature management. Scania's Euro 6 developments, building on its advanced Euro 5 engine designs, include an intake throttle – mounted between the charge cooler and the intake manifold, downstream of the turbo compressor and the intercooler – which is used in tandem with the exhaust brake to optimise temperatures reaching the exhaust after treatment.

## Euro 6 emissions directive in detail

Euro 6 imposes the most draconian cuts in allowed emissions from heavy-duty diesel engines, in terms of NOx and particulates (soot) – with NOx limited to 0.4gm/kWh (down 50% from Euro 5) and particulate mass (PM) restricted to 0.01gm/kWh (a cut of 80% against the current Euro 5 requirement). On top of this, the European Commission has now ratified a maximum particulate number (PN) loading of 6.0 x $10^{11}$/km – making the addition of costly full-flow DPFs (diesel particulate filters) almost inevitable when the new regulations come into force in December 2013.

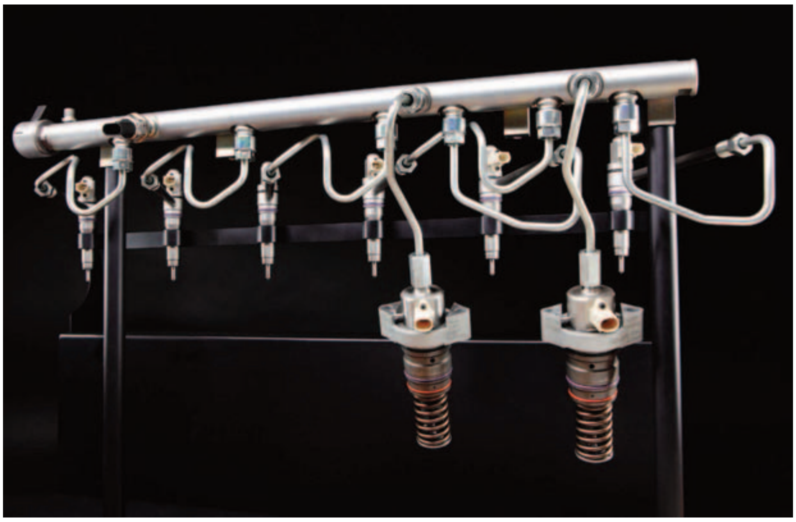
As for accreditation, agreement has been reached that testing will be to the WHTC (world-wide harmonised transient cycle), which overall forces a lower loading than the ETC (European transient cycle) used to validate engine emissions for the current Euro 5 regulations. While a good decision by the EC – in line with the clear trend amongst operators to cut fuel consumption and hence costs, with drivers trained and monitored to operate trucks less aggressively – it does make passing the test harder for SCR (selective catalytic reduction) after-treatment systems, simply because exhaust gas temperatures tend to remain lower for longer.

However, there are two further issues: one mandated under Euro 6; the other, as yet, still in the offing. The former concerns onboard diagnostics (OBD), which have to step up a gear. Under Euro 6, the EC requires truck manufacturers to enforce maintenance of Euro 6 emissions performance in operation, right out to seven years or 700,000km. Put simply, the diagnostics must alert the driver to anything on the engine or the after-treatment system causing tailpipe emissions to drift out of spec. Further, engine controls must also encourage urgent action, if a problem is detected, by progressively (but also safely) limiting torque until the problem is fixed.

Beyond this, the systems must also be tamper-proof (and expressly capable of alerting the authorities of any breach) and the truck OEMs must also provide standardised fault codes, accessible by any diagnostic system and capable of quickly pointing technicians to the source of any problem.

Finally, although specifically not covered under Euro 6 emissions legislation, it is only a matter of time before carbon dioxide becomes a target for serious emissions reduction. Best guesses in the industry – supported by soundings from ACEA (European Automobile Manufacturers Association – are a 20% reduction, compared with current $CO_2$ levels. That is going to present a serious challenge, given the difficulties already experienced by engine system designers in mitigating increases in fuel consumption (and hence also $CO_2$ emissions) necessitated by the increased drive for NOx and particulates reductions, on the move from Euro 5 to Euro 6.

Current ideas include further reducing friction and parasitic losses in engine designs, as well as moving more towards electrically-operated auxiliaries and eventually also recovering at least some exhaust waste heat energy. The latter is certainly not trivial, and industry pundits estimate a combined improvement of no greater than 10% is feasible. After these, it seems like another look at dual-fuel and then redoubling of efforts away from the engine itself in areas such as aerodynamics and low rolling resistance tyres could be close.



**Delphi's F2 fuel injection technology is currently being validated and performance optimised**

Returning to the injection systems, though, opinion is divided as to quite how far engine designers need to go with multiple injections. Ricardo's Such makes the point that, while developers talk of anything from five to 17 pre- and post-injections, calibrating and optimising more than five is likely to lead to diminishing returns. That said, he agrees there is considerable and proven scope for improving heat release – essentially as a result of better fuel-air mixing in the cylinder – as well as increasing exhaust temperature to improve performance of the SCR phase, while also reducing soot emissions.

However, other interesting developments concern the combustion chamber itself. Although currently aimed at off-highway applications, Ricardo's TVCS (twin vortex combustion system), for example, looks very promising – and potentially also for on-highway trucks. Such explains that the development, which builds on work with today's high pressure common rail systems, is aimed squarely at reducing soot emissions in the combustion chamber itself. It does so by improving the distribution of fuel and air mixing during injection and combustion, using an adapted bowl shape that more closely matches spray patterns from the injector nozzle.

"Using TVCS, we've already been able to reach the Euro 6 PM [particulate mass] targets of 10mg per kWh, without using a DPF or after-treatment at all – but not yet the PN [particle number] requirement," states Noble. And he continues: "Currently, we're adding our TVCS knowledge to on-highway applications. We're at the early stages, but we're optimistic that we can bring benefits, in terms of fuel consumption, in the not too distant future.

"At the very least, there would be less work for a DPF, so it would be possible to use a smaller unit. Also, with the higher NOx-to-soot ratio we're generating, you get a lot of passive regeneration in the DPF – meaning you don't need to go to thermal [active] regenerations, which, in turn, saves fuel."

### Electronic strategies

That brings us to the control electronics and strategies, and the primary issues are, as ever, twofold: first, managing the base engine and its air-gas flows, including through the EGR system; and secondly, SCR system controls in the after-treatment section. Looking at the former, it's all about managing the EGR valve and the VGT (variable geometry turbo compressor), if there is one, as well as any intake throttle valves.

"The electronic system needs to optimise boost pressure and EGR rate to the engine conditions, while also achieving low NOx and particulate emissions, and ensuring good engine transient response, without lag," explains Noble. And to do that, the industry is mostly now turning to real-time computer model-based control approaches that learn from simulations.

It's much the same story for the after-treatment controls, with embedded electronic models providing for ultra-precise AdBlue dosing. "It's always a balancing act," agrees Noble. "Under-dose and you get poor NOx conversion; overdose and you get ammonia slip, which is unacceptable and limited under Euro 6. So the control system needs to manage the level of urea in the SCR, taking real-time data from sensors, usually monitoring tailpipe NOx and temperature."

With just two years to go before Euro 6, watch this space for further mechanical and electronic developments in diesel engine injection and combustion management systems.

## Common rail for the real world

When it comes to common rail systems for truck engines, Delphi Diesel Heavy Duty Systems is one to watch. Its F2 fuel injection systems – introduced at last year's IAA exhibition in Hannover, and currently being validated and performance optimised – don't just include the conventional common rail arrangement, with remote pumping.

At least as important are its additional options specifically designed to fit on to existing EUI (electronic unit injector) cam-in-head, or EUP (electronic unit pump) cam-in-block type engines. As chief engineer Andrew Knight explains, these are receiving considerable attention precisely because they eliminate consequential changes to OEMs' existing engines.

"The point is that OEMs don't need to adjust the dimensions or layout of their existing engines, so we're bringing all the advantages of common rail, with none of the disadvantages," states Knight. "We have a lot of systems running already on validation test rigs here at Delphi, as well as many others on engines in the field. All of them use our patented, miniaturised valve technology, which precisely controls the flow of high-pressure fuel to the rail or injector nozzle," he adds.

That's the theory, but Knight states that Delphi's new common rail systems have also been designed to run to original precision for at least 1.65 million km. Much of that development builds on Delphi's experience with its twin valve E3 EUI, which already operates at 2,500 bar, with the firm having spent almost five years refining the technology at its Park Royal technical centre in London. Knight talks of systems currently being optimised for medium duty (4–9 litre) engines and heavy-duty (9–16 litre) applications, the former with 'slimline' 21mm injectors or combination injectors.