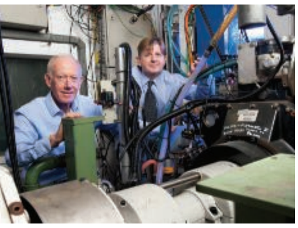
CUTTING CO_2 EMISSIONS

With Euro 6 a done deal, you might imagine that engine technology must now be stable? Well, no. Reducing CO_2, and saving fuel, is the next big EC target. Brian Tinham reports

Stringent Euro 6 emissions limits – and the mandated seven-year service compliance – meant serious changes for heavy-duty diesel engine design. Fuel injection systems, EGR (exhaust gas recirculation) packages, the associated boosting strategies and equipment, after-treatment assemblies... The list (and the expense, sophistication and additional weight) goes on and on. But, after spending billions of euros on R&D and production engineering, all the truck and engine OEMs met last January's deadline – only to be rewarded, in the UK at least, with collapsing sales, following the run on their Euro 5 predecessors.

However, while developers doubtless breathed a collective sigh of relief at the technical goals achieved – and operators grudgingly accepted the new reality – the EC (European Commission) has quietly but relentlessly moved on. Not, it seems, to further vanishingly small NOx and particulates reductions, as expected by some for a notional Euro 7. Instead, Europe's attention has largely migrated to global warming and transport's over-production of damaging greenhouse gases from fossil fuels. So, behind the scenes the race now being set is for yet another breed of emissions-busting engines, but this time aiming for substantial cuts in CO_2 (along with nitrous oxide and methane). Yes that equates directly to fuel saving, which is good news, but the due date is around 2020 – just six years from now.



So what's going on? Well there are several strands of R&D work, the most impressive including the US Department of Energy-sponsored SuperTruck project, as well as the EC's NOWASTE (focused largely on waste heat recovery) and CORE (CO2 reduction) initiatives – each of the latter being supported under Framework 7. Looking at near-term combustion and injection technologies, CORE – two years into its four-year duration – seems most promising, with its target of a 15% improvement in fuel economy (and hence CO_2) over new Euro 6 engines. Expectations are: 6–9% through engine, powertrain and fuel developments; 3–5% from hybrids; and 2–4% from engine friction reduction and more energy-efficient exhaust after-treatment packages.

Chris Such and Andy Banks (pictured), both chief engineers in the heavy-duty diesel team at world-renowned Ricardo, explain that CORE is essentially divided into six sub-projects. Three focus on engine and powertrain platforms: optimising existing diesel engines in terms of combustion, air management and after-treatment; down-speeding engines; and optimising hybrid-electric layouts as well as implementing alternative fuels – notably CNG/LNG (compressed/liquefied natural gas) – combined with variable valve actuation (VVA).

Two more sub-projects provide cross-project support, working on friction reduction and improving NOx after-treatment systems' low-temperature performance. And the sixth concerns knowledge and technology transfer, with results being evaluated by vehicle simulations in terms of meeting CORE's fuel economy targets.

Projects in depth

Stepping through each, Daimler and Hanover University are leading the first, using a six-cylinder Euro 6 Mercedes OM936 360bhp 7.7-litre mid-duty engine with two-stage turbocharging, and focusing on a combination of hybridisation and down-speeding. Such makes the point that to operate successfully at lower engine revs, torque needs to increase in the lower range, which means higher peak cylinder pressure (PCP) and hence implications for critical engine components.

That said, simulations to date suggest an 8.8% improvement by adding in a parallel hybrid system, and a further 2% by down-speeding from 2,200 to 1,800 rpm. "The potential of down-speeding has been investigated in single-cylinder engine tests, varying injection timing, rail pressure, boost pressure and EGR rate," explains Such. "The analysis of power losses showed that the advantage of down-speeding was due to reduced gas exchange work and reduced friction."

The second sub-project is being led by Volvo Trucks, working with Honeywell Turbo Technologies, Johnson Matthey and Chalmers University, together researching new boundary conditions for high-efficiency, long-haul diesel engines. Their starting point is higher PCP, and the addition of VVA with a

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re-optimised two-stage turbocharger and higher efficiency after-treatment.

Banks says this combination is required to enable advanced combustion strategies, leading to the desired reduced CO_2 emissions via application of the Miller cycle (using early or late inlet valve closing) and down-speeding, as well as an improved NOx versus soot trade-off. Simulations to date suggest a 5% improvement against a Euro 5 engine benchmark – so probably somewhat less than that against Euro 6. As for this team's work on higher-efficiency after-treatment packages, this has been geared mainly to maximising passive regeneration of DOC/DPFs (diesel oxidation catalyst and particulate filter) by looking at alternative coating technologies that both improve oxidation and reduce back pressure.

Meanwhile, the third project – examining advanced combustion systems on diesel and natural gas engines – is under Fiat, Europe's JRC Science Hub, Metatron and Turin University. This team has been harnessing VVA on a Cursor 9-litre diesel and Cursor 8-litre gas engine, which have the same cylinder head architecture, with a single overhead cam. To date, they have built and tested (on a valve train test rig) a hydraulic system to control valve lifting.

On the gas engine, VVA improves fuel economy by 2% at high load and speed, but up to 10% under easier conditions, because it reduces or eliminates the need for inlet throttle – in turn cutting parasitic pumping losses. It also delivers higher torque at lower engine speeds and reduces exhaust temperatures across the curve. Banks concedes it remains to be seen whether the effects on diesel engines will be as impressive, but suggests that additional changes to the EGR side should help.

Moving on to the cross-projects, Ricardo, working with Federal-Mogul and Daimler, is aiming to reduce FMEP (frictional mean effective pressure) by 10% through developments with reciprocating (and some rotating) components plus new lubricant additives – again alongside engine down-speeding. So far, Ricardo has modelled and validated frictional characteristics of the sub-project base engines, and used that data to predict best piston and ring re-designs for optimal FMEP.

Those have been produced by Federal-Mogul and are now due for testing, first on the base engines and later on a revised, down-speeded engine from the Daimler project, where they will experience higher PCP. Such believes 30–40% reduction in FMEP is likely for the reciprocating components, provisionally suggesting a reduction in FMEP for the whole engine at full load of 10–20%, or 10% when cruising. And he adds that work on another project has demonstrated further benefits by using low-viscosity lubricants with advanced additive packs – to the tune of 11% when

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cruising, 8% at minimum load and 5% at full load, compared with a 5W 30 oil. Those figures, he asserts, equate to around 1% fuel consumption improvement over the WHTC (World Harmonised Test Cycle).

And finally, back on after-treatment, the other cross-project – which involves IAV, Fiat, Milan University, Solvay, Umicore and Daimler – is investigating opportunities for CO_2 reduction by integrating SCR (selective catalytic reduction) much more tightly with the engine, while also evaluating different SCR catalyst formulations (alternative metal oxides) and susbstrates capable of improving low-temperature NOx removal performance.

To date, the developers have modelled alternative technology constructions, including SDPF (where the DPF itself includes an SCR coating), assessing their ability to process higher levels of NOx and hence fuel reduction. Such says that, while SDPF does show promise, the greatest improvements, surprisingly, have come from increasing the AdBlue additive ammonium nitrate, and moving up to a higher SCR cell density, which enhances catalyst activity.

Trade-offs and optimisation

So far, so good. But putting meat on these projects' bones, our Ricardo chief engineers point to a mix of challenges and trade-offs in further improving diesel engine efficiency within the constraints imposed by Euro 6. Such points to the issue of reducing friction: "One of the trends in recent years has been to increase PCP to maximise engine performance while also improving fuel consumption – because, for example, you can operate with more advanced timings. Maximum cylinder pressures are now about 200bar, but in future they could be 240–250bar."

That means big changes in cylinder and piston crown design with greater use of CGI (compacted graphite iron) for the cylinders and steel for the pistons, along with new cooling strategies. "But reducing friction, using new piston ring designs and skirt profiles, could easily compromise the new pressure and durability goals," says Such. "So it's all about optimisation around the trade-offs, and then friction modelling and validation."

Hence his assertion of 1% from frictional improvements due to piston ring and associated redesigns, plus a further 1–1.5% from lower-viscosity lubricants. And note that the latter isn't as cut and dried as it might seem. "On very high rated engines, reducing viscosity doesn't necessarily reduce fuel consumption, especially at high loads. That's because the piston rings, etc, run in 'boundary lubrication', meaning there is some metal to metal contact. So, currently we're looking to oil and additive companies to reduce friction in these conditions."

What about down-speeding? Banks emphasises that making this work requires remapping the torque curve to peak in a narrow, lower-rev band. "At the moment, maximum BMEP [brake mean effective pressure: a measure of engine performance independent of swept volume] is about 25bar, but for a narrow band we might need 27–28bar [equating to 250bar PCP], maybe even higher. So, again we need to look at building engines to cope with higher cylinder pressures. The higher pressure allows the engine to run more efficiently and more powerfully, but that in turn demands more fuel – so higher pump rates and greater parasitic losses. They also require more air – so more sophisticated boosting technology, which isn't cheap."

Again, the trade-offs. Banks reminds us we are reaching the limit of single-stage turbocharging for heavy-duty engines. "Both wastegates and VGTs [variable geometry trobochargers] have been widely incorporated into Euro 6 engines – although SCR units generally require less complex designs, because cylinder pressures are lower. But we're now seeing a requirement to move back to two-stage fixed-geometry turbochargers [symmetric and asymmetric] or novel high-pressure ratio single-stage units."

That's despite the likelihood that future engines will see EGR decline – meaning designers can focus back on turbocharger efficiency. "They're more expensive, but also there are questions such as, do you need intercoolers on two-stage compressors?"

Perkins manages without an intercooler on its latest two-stage tubocharged engine, using a titanium compressor wheel instead. Admittedly, that's off-highway. For a heavy-duty truck, Banks says the minimum would be some kind of pre-cooler. Either way, increasing boost capacity costs money. And that flies in the face of OEMs' work on cost-reducing base engines, particularly at Euro 6, because of the sheer expense of the after-treatment packages.

It's a similar story with fuel injection systems on the route to improving fuel economy. Such explains that Ricardo is looking at pressures up to 3,300bar on its test bed single-cylinder R&D engine. The team is also investigating the impact of multiple injections ("up to five") over the course of TDC, not only to improve fuel consumption, but also to find the best compromise between burn efficiency, noise and mechanical stress.

"If we can realise better fuel consumption from improved atomisation then we'll take that benefit," says Such, "as long as it beats the fuel pump losses and the FIE [fuel injection equipment] manufacturers can prove durability of their high-pressure systems, for example in terms of preventing nozzle coking."

As for the after-treatment, both he and Banks note that, although SCR has been around in heavy-duty diesel for several years now, there is still scope for improvement. That's in terms of both the equipment geometry, but also the efficiency of mixing of the exhaust gases and AdBlue across the catalyst face.

"With the adoption of DPFs, we see the whole system as now ripe for re-optimisation," explains Banks. "The OEMs did a lot of work on their after-treatment systems on the run up to Euro 6, but they present a significant resistance to the flow of gases through the engine, and that amounts to a major parasitic loss. That's why, under CORE, we're looking at reducing the DPF's back pressure to improve its contribution to CO_2 performance – but, again, taking into account the compromises involved in achieving very high DPF efficiencies to minimise regeneration, while also considering combustion efficiency and engine-out soot over the transient cycle."

Who thought we were done with engine developments for now? TE

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