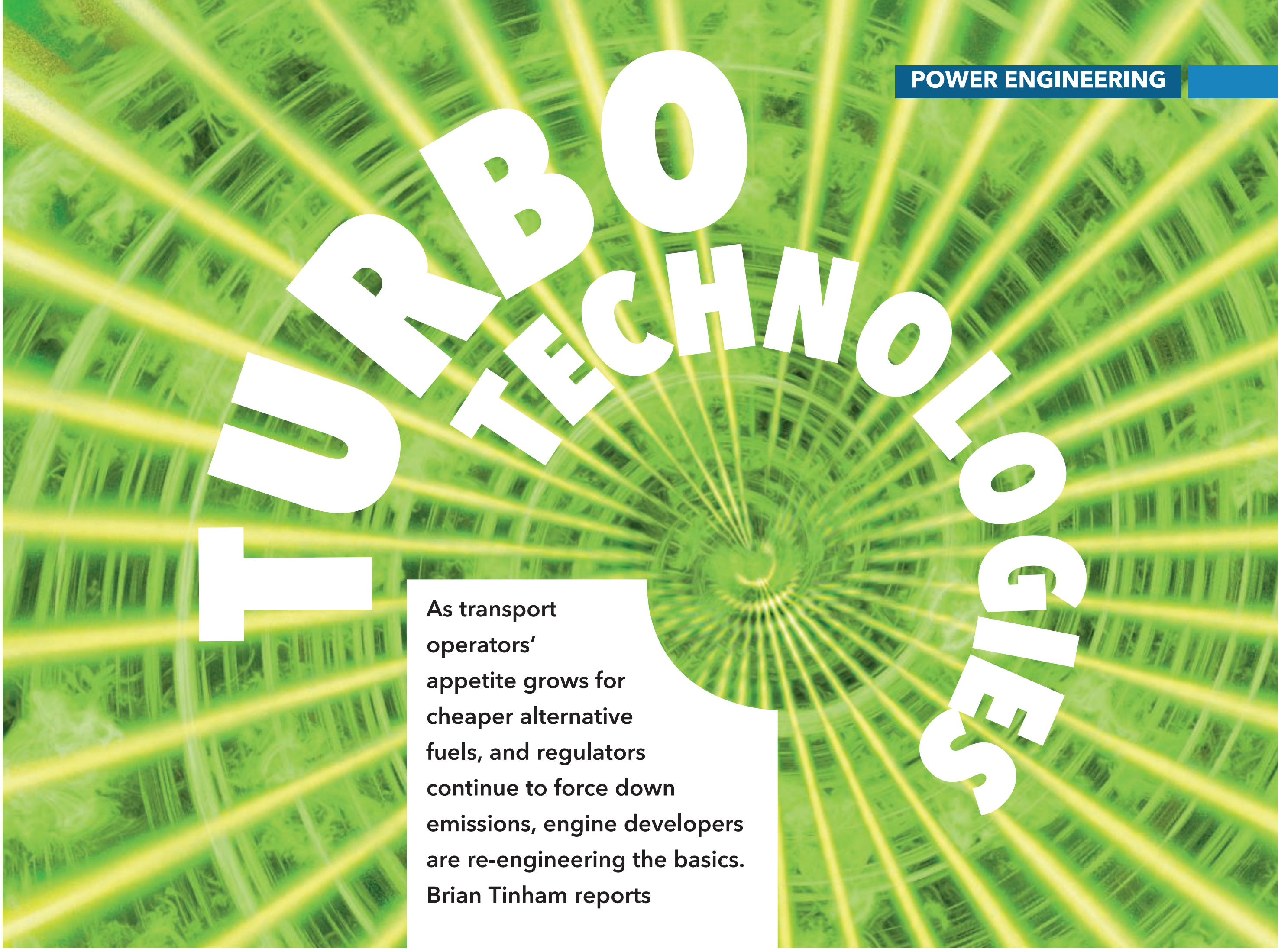

TURBO TECHNOLOGIES

As transport operators' appetite grows for cheaper alternative fuels, and regulators continue to force down emissions, engine developers are re-engineering the basics. Brian Tinham reports

Commercial vehicle power plant development isn't just about optimising for emissions in the face of stricter EU limits. Nor is it only concerned with injection strategies to improve combustion efficiency and/or enable alternative fuels, such as L/CNG (liquefied/compressed natural gas), that respond to the green agenda. Both are important, but so are engine downsizing and downspeeding as operators continue to demand reductions in fuel consumption. And so the list goes on.

All of this has implications throughout the engine envelope. Increasing pressures and temperatures, for instance, are taking some components beyond design limits. That applies all the way from pistons and rings to cylinder heads and blocks. And the same applies to auxiliaries, particularly turbochargers that are literally in the firing line. Engineers need not only to reconsider mechanical integrity, but also to challenge surface-coating techniques and ultimately material science itself.

So it's interesting to look at a couple of recent turbo projects completed by heavy-duty engine specialist Cummins. One was a response to predicted growth in alternative fuels, particularly natural gas, with its known impact on exhaust gas temperatures. The second concerns increasing interest in long-route exhaust gas recirculation (LR EGR) as an in-engine NOx reducing technique, and its corrosion and erosion implications for boost components.

SPARK IGNITION

Taking the L/CNG project first, Dr Andrew Sullivan, principal engineer with Cummins Turbo Technologies, explains that it's all about spark ignition, citing Cummins' work with Westport under the joint venture currently developing heavy-duty engines up to 15 litres displacement. He acknowledges that Cummins has a long history delivering turbos for natural gas applications, but reminds us that most have been on lean-burn engines, which operate with similar characteristics to their diesel counterparts. Much the same applies to dual-fuel conversions.

"Stoichiometric gas engines are becoming increasingly popular [and] this mode of operation has a significant impact on the turbocharger," he says, pointing to data logs of diesel versus natural gas turbine inlet temperatures (TITs), which show the latter running higher for much longer periods. "Elevated TITs can have a detrimental effect on the life of the turbine stage components – possible reduction in TMF [thermo-mechanical fatigue] life being one example," he explains.

Quite simply, fixed-geometry and wastegate turbos have been designed to operate at up to 760°C but with mean temperatures closer to 600°C, using inconel-based super alloys. With spark-ignition L/CNG engines, operating temperatures are getting close to that design limit. "We're not saying all applications will run at very high temperatures, but we're scoping for a jump in capability of 100°C – so 860°C."

That turns out to have been

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ambitious. Indeed, Cummins' laboratory has now been upgraded with test equipment capable of handing 1,000°C. "We don't see exhaust gas temperatures rising to that level, but we are expecting incremental rises so 900–950°C," he says. "So the new facilities stand us in good stead – including for fuels such as E85 [85% ethanol, 15% petrol]."

So Sullivan's team took a multi-faceted approach, starting by reviewing data from duty cycles on operator routes using diesel and gas vehicles. Where component metal temperatures were difficult or impossible to obtain, Sullivan worked with Spain's University of Valencia on a lumped-capacitance heat transfer model (already widely used in car simulation, but a first for heavy-duty vehicles) to estimate turbocharger housing thermal responses.

That data was then plugged into stress- and strain-based TMF simulations (the latter, using HBM's nCode software) to derive precise component durability for a variety of material classifications across the duty cycles. "While the stress-based method is limited in its applicability, the strain-based approach has been shown to correlate well with durability testing on alternative materials subjected to increased exhaust gas temperatures," comments Sullivan.

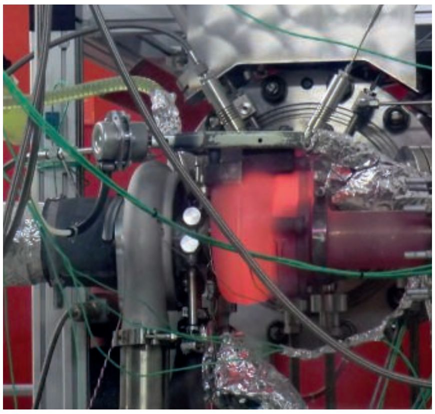
The result: numerous turbocharger systems and components have now been tested and several materials considered and validated, he says. On the way, each of the failure modes has been investigated – not only TMF, but also LCF (low cycle fatigue), HCF (high cycle fatigue), creep, joint relaxation and rotation, wear and corrosion.

So far, so good. What about Cummins' LR EGR research? Group leader Dr Michael Burkinshaw explains that, while high-pressure, short-route EGR remains dominant, there is an opportunity to improve fuel economy using the low-pressure, long route. That is because of improved homogeneity in the mix of EGR gas and intake air, as well as reduced pumping losses. However, just as valuable, all important NOx emissions are typically reduced because of cooler charge temperatures.

LONG ROUTE EGR

Hence the growing popularity of LR EGR among car engine designers, and hence also Cummins' decision to examine requirements for up-scaling the technology to heavy-duty. As Burkinshaw says, there were always going to be challenges – and they're not just about the increased costs and weight associated with pipework and filtering. First, the turbo impeller is subject to significantly greater erosion, due to particles in the EGR gas. And second, the whole compressor stage sees heightened corrosion as a result of acidic condensate formation.

"So our work was aimed at establishing appropriate compressor materials and coatings for aggressive LR EGR environments," he says. In fact, untreated and surface-treated aluminium alloy impeller and compressor cover materials were characterised, using a mix of high-resolution microscopy, chemical analysis and interferometry, etc, all designed to deliver accelerated test cycles – not only to cut costs, but also to improve testing repeatability and the data accuracy.



Burkinshaw says surface treatments evaluated included anodising, plating and polymeric, with substrates subjected to particle erosion and condensate corrosion tests developed using data from literature and on-application experience. In terms of erosion, particle size and density were both considered, he adds, while for corrosion testing, condensates of varying pH were used to replicate the range. And he explains that aerodynamic performance, fatigue strength and thermal capabilities of the untreated and surface-treated aluminium alloys were also compared – along with adhesion characteristics and thermal shock behaviour.

As for the results, Burkinshaw gives little away, saying only that an anodising treatment scored highest for LR EGR impellers, due to its non-porous and uniform microstructure, as well as its strong adhesion. Moreover, it afforded superior wear resistance compared to alternatives evaluated, while aerodynamic performance and fatigue behaviour remained comparable to the baseline impeller.

Meanwhile, two surface engineering concepts involving spraying and plating were chosen to protect the compressor cover, primarily because of their corrosion resistance. Interestingly, the team also identified an alternative aluminium alloy for the compressor body for its improved performance and durability.

"The research has been published and we are now providing prototypes for LR EGR testing by our customers," confirms Burkinshaw. "Think of these turbochargers as technology enablers. The dimensions are exactly the same as their conventional predecessors. Their characteristics are very well known. Trials are already underway... LR EGR turbochargers should be available by the end of the 2010s." TE