Turbo Technologies

HTi

The Latest Turbocharger News

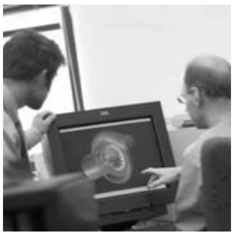
Axi-Radial High Pressure Ratio Turbocharging

EDITION 11:

P3
The Commercial Vehicle Market in India

P5
The Influence of Duty Cycle on Turbocharger Life and Performance

P11
Planning for Service and Serviceability



Executive Comments

This, the eleventh edition of HTi, provides a diverse range of the technical, manufacturing and business techniques that we are using at Cummins Turbo Technologies. We begin by looking at the fail-safing techniques at our Palmetto facility in Charleston, USA and find out how we use an approach called Poka-Yoke to improve quality.

Many of you will be aware of the recent economic slowdown in the global markets. In this issue of HTi we explore the Indian market, with a detailed analysis of its truck market. Rapid growth in Indian truck sales has faltered recently but there is no doubt that this is just temporary due to a number of major European and Japanese truck manufacturers moving into the country to establish production. With the opening of our second turbocharger plant in India, at Pithampur, we are ready to meet the demand. Despite this recent economic uncertainty, Cummins Turbo Technologies is continuing to invest in engineering throughout its global facilities.

Through its technical excellence, Wuxi Cummins Turbo Technologies continues to progress as the market leader in the medium to heavy-duty turbocharger market. A new technical centre has just been opened and the three-millionth turbocharger was produced in June this year.

Speed cycling is a key determinant of turbocharger life and performance, so when asked to provide turbochargers for a new application, our engineers need to understand its duty cycle. In this issue of HTi, we describe how we do this and what we look for.

Engine manufacturers today request higher turbocharger pressure ratios and so two-stage systems are increasingly popular. However, there is an alternative and on pages seven and eight we describe the axi-radial compressor, capable of high pressure-ratios without bulkier, more complex two-stage turbocharging.

The End-of-Life Vehicles directive compels the European automotive industry to make it easier and safer to recycle vehicles due for scrapping. Cummins Turbo Technologies is playing a part in this drive to consider the future environment by adopting new materials.

Mark Firth

Did you know that Service Engineering has a major input into our turbocharger design and product release processes? Our Service Engineering Manager describes how his team ensures that new products are launched with the best service support in place from day one.

The true test of customer satisfaction is customer loyalty. This is the underlying principle of the Net Promoter Score (NPS), a technique we are now exploring. HTi explains the theory of NPS.

We conclude this issue of HTi with an overview of our participation in four of the big automotive shows and events promoting our industry-leading technology and expertise.

Mark Firth
Executive Director; Research and Engineering

Editorial

Editor: Alison Smith (email: alison.j.smith@cummins.com)
Assistant Editor: James Moorhouse (email: james.moorhouse@cummins.com)
Editorial Team: Owen Ryder, Jodie Stephenson, Gillian Murray
Copywriter: David Wilcox
Email: turbo.enquiries@cummins.com

HTi is the Cummins Turbo Technologies magazine focusing on the world of medium and heavy-duty turbocharging. It aims to bring you news on product and market developments.

Publication design by Media Mill Ltd. +44 1457 877 164

Celebrating
Technical Excellence in China

Written by ChunZhe Song; Marketing Manager

China has faced unprecedented change over the last decade. It now has one of the world's largest economies, with its gross domestic product (GDP) growing at almost 12% in 2007. Performance in the industrial sector was even more impressive, with growth of 48.6%.

The sheer size of the market, coupled with this rate of growth, makes China a highly attractive proposition for major foreign industrial players, jostling for a share of this lucrative business. Cummins Turbo Technologies has chosen to differentiate itself from the competition by concentrating on achieving technical excellence through its joint venture in China, Wuxi Cummins Turbo Technologies.

Presentation of the three millionth turbocharger

On 11 June 2008, Wuxi Cummins Turbo Technologies officially opened the second phase of its facility at Wuxi. This includes a state-of-the-art technical centre, opened just one year after the plans to build it were revealed. This is testament to the hard work and determination of our employees in China.

In addition to its testing facilities, the new technical centre has a range of engineering departments including application engineering, design engineering, reliability, research and Value Package Introduction (VPI) project management. This new facility will not only increase our technical capabilities but also enable us to provide better, quicker and more accurate responses to our global customers.

Following the official opening ceremony, Wuxi Cummins Turbo Technologies held three open days for its customers, giving them an insight into capabilities now available at Wuxi. Senior management and engineers from companies such as Weifang Diesel, Wuxi Diesel and China National Heavy Truck Company (CNHTC), together with executives from Cummins Turbo Technologies, were among those who toured the technical centre for a closer look at what it has to offer.

Customers visiting the new Technical Centre

It was during one of these customer visits that Wuxi Cummins Turbo Technologies celebrated the production of its three millionth turbocharger. This milestone is another demonstration of the progress and achievements in Wuxi. The one millionth turbocharger was produced eight years after the plant was opened; the two millionth was made after a further three years. The three millionth turbocharger came off the production line just 15 months later.

During the event to mark production of the three millionth turbocharger, Michael Cummings; Chief Engineer, Wuxi Cummins Turbo Technologies and Paul Ibbotson; Vice President, Components Business Development, gave customer presentations about the latest turbocharger technology and Holset products, including new Holset VGT™ models.

These few days of activities not only provided a platform to highlight our emphasis on technical excellence in the important Chinese market but also gave us an opportunity to develop and strengthen relationships with our customers.

The Commercial Vehicle Market in India

Written by David Wilcox; Deputy Editor of Transport Engineer Magazine

Following on from HTi Issue 10, where we looked at the European truck market, David Wilcox investigates the Indian market, looking at how the recent economic down turn is effecting the commercial vehicle market.

India has one of the fastest growing economies in the world, with gross domestic product (GDP) expanding at an average annual rate of over 8% in recent years. Burgeoning numbers of trucks and vans on Indian roads are evidence of this economic boom. Commercial vehicle sales have grown by an annual average of 26% in the 5 years between 2002 and 2006; however in the 12 months to 31 March 2008, sales grew by only 4%. This sluggish growth rate continued in the first four months (April to July) of the current fiscal year but then the market collapsed in August, with manufacturers reporting double digit percentage falls in sales of medium and heavy-duty trucks. Production has been cut back accordingly. Has the massive Indian commercial vehicle market stalled?

Analysis of the Indian truck market reveals a marked structural change between 2002 and 2006. Sales of heavy-duty trucks (over 16.2 tonnes gvw) grew strongly at over 35% year-on-year. Sales of light commercial vehicles also flourished, particularly those below 3.5 tonnes gvw. Demand for mid-range trucks in between has been squeezed. This polarisation stems from the development of interstate highways that make long-haul road freight more viable, rivalling the famous Indian railways. Hub-and-spoke road freight distribution is evolving; calling for big articulated trucks for long-distance trucking, supplemented by light commercial vehicles for final deliveries.

Another stimulus for heavy-duty truck sales came in November 2005 when the Indian Supreme Court ruled that all India's state governments must adhere to national rules on truck gross weights. Many of India's 28 state governments previously sold permits allowing trucks to be grossly overloaded. The court ruling quickly forced operators to turn to bigger trucks. In the year from April 2006 to March 2007, sales of medium-weight trucks grew by just 5% whereas heavy-duty truck sales rocketed by 70%.

After such a turbulent period, the commercial vehicle market was expected to slow in the following year to March 2008. Nevertheless, growth of just 4% overall was rather less than anticipated. The only bright spot for heavy-duty trucks was strong demand for multi-axle tippers, serving the buoyant Indian construction industry. Indeed, the total Indian tipper market is forecast to rise by 35% over the next five years. Sales of light-duty commercials were resilient, up by 12% but the medium and heavy-duty truck sector fell by almost 2%. Several factors contributed to this lacklustre overall performance. It is alleged that overloading has returned in some states, dampening demand for bigger trucks. There has been a series of interest rate hikes, so finance for fleet expansion and renewal is expensive. A shortage of truck drivers is also reported.

INR

The deep depression that hit the Indian truck market in August is attributed to a combination of all these factors, compounded by an economic slowdown in the country. Manufacturing GDP in the quarter from April to June 2008 was up by just 5.6%, compared with 10.9% in the same quarter a year earlier.

India is currently between tiers of heavy-duty diesel engine emissions legislation. India follows European emission limits but is several years behind. Bharat Stage II (equivalent to Euro II) took effect throughout India in April 2005 but in 11 big cities it was Bharat Stage III (equivalent to Euro III) that was implemented on that date. These cities have poor air quality; in 2005 the ambient level of PM10 particles in Mumbai was 4 times the maximum value recommended by the World Health Organisation. The really big reduction in particulate emissions begins in April 2010 when new commercial vehicles in these 11 cities must comply with Bharat Stage IV (Euro IV), cutting the particulate limit by a further 80%. The rest of India adopts Bharat Stage III on that date.

Stringent emission standards will see India accept more sophisticated technology, which it has previously resisted. Indian truck operators prefer simple engineering that is easily repaired. Most new trucks in India are equipped with drum brakes instead of discs; their suspension is steel leaf, not air. European trucks have made few inroads in India because they are perceived as too sophisticated and too expensive.

This technology and price gap between Europe and India is now being bridged by Indo-European joint ventures manufacturing trucks tailored to the Indian market. They have enough but not too much technology to demonstrate progress and producing them in India keeps costs in check. The Indian partners in these joint ventures benefit from accelerated technical development while their European partners get a stake in a market too big to ignore. Tata Motors signed a memorandum of understanding last year with Italian truck maker Iveco to examine the feasibility of co-operation, likely to involve Tata selling Iveco heavy-duty trucks in India. In August, Indian manufacturer Eicher Motors transferred all its truck and bus building operations into a new 50/50 joint venture with Volvo Trucks. The joint venture company, called VE Commercial Vehicles, also contains Volvo's Indian truck sales and service operations.

Daimler of Germany signed a joint venture agreement in April with Indian industrial conglomerate the Hero Group, establishing the Daimler Hero Motor Corporation. The two partners have since agreed to build a new truck plant in Chennai, where production of trucks carrying a new brand name is due to begin in 2010. Initial production of up to 70,000 trucks a year will be for the Indian market, with exports planned for the future. MAN of Germany is already firmly established in India, through a joint venture with local manufacturer Force Motors. Production of trucks started at MAN Force Trucks in Pithampur in late 2006 in a plant with an annual production capacity of 24,000 a year. The trucks, with gross weights of between 16 and 49 tonnes, have European origins but are tailored to the Indian market. Exports from the plant started in the last quarter of 2007.

It is not just European truck makers who are intent on doing business in India. In September, Japan's Hino Motors announced that it plans to start selling trucks in India next year. It aims to sell 2,000 in the first year, rising to 20,000 by 2013. If it meets these targets, Hino says it may even build a plant in India. International of the USA has also struck a joint venture with Mahindra called Mahindra Navistar Automotives Limited (MNAL) and is setting up a plant near Pune. Production of trucks between 3.5 and 49 tonnes gvw is due to start in the last quarter of 2009.

None of these big global players would have been so eager to establish footholds in India if they were not convinced that there is good growth potential there. Although analysts have revised their GDP forecasts downwards in the light of the financial and economic turmoil affecting many parts of the world, most still expect the Indian economy to rise by about 7.5% in the current financial year. When so many countries are tipped to flirt with recession, that still looks like a very healthy figure. This strong underlying economic growth trend suggests that the Indian commercial vehicle sales graph will soon turn upwards again.

Cummins Turbo Technologies is well placed to meet India domestic demand as well as exporting to other parts of the world. Construction work on its second Indian turbocharger manufacturing facility, based it Pithampur began in January 2008 and is now nearing completion. The official opening ceremony is already being planned. The Pithampur facility is to produce high horsepower and mid-range turbochargers.

The Pithampur plant is set to revolutionise manufacturing standards of Cummins in India. For example, it will be the first Cummins manufacturing site in India designed with consideration for access for disabled people. Safety too is incorporated at the design stage. Among the many examples of this is the installation of systems that eliminate the need to use fork-lift trucks within the building.

The Influence of Duty Cycle on Turbocharger Life and Performance

Written by Jim Olmstead; Applications Engineering Manager

How do you take a truck engine and adapt it to work in a mine? How should we select a turbocharger to give optimum life and performance on a snow groomer working 2,000 metres up in the mountains? What are the engine characteristics of a mechanised grape-picker?

These are the type of questions that our customers are asking us at Cummins Turbo Technologies. They look to us to provide technical expertise and reliable solutions to meet all their turbocharging needs, no matter how unusual their applications may be.

So, how do we go about it? What are the key factors that we consider when specifying turbochargers in new applications? The answer always lies in a thorough understanding of the duty cycle of the equipment, of its engine and of its turbocharger.

Holset turbochargers are designed to operate in a wide range of applications and operating conditions. Provided they are looked after, they will normally last as long as the engine; but this is neither a 'one size fits all' nor a 'one design does everything' business. The reality is that the reliability and durability of a turbocharger is influenced by the way in which it interacts with the engine and the way in which the engine is used - its duty cycle.

The most widely quoted factors that influence the working life of a turbocharger are its maximum speed and turbine inlet temperature. Although both are very important, these are by no means the only determinants of lifespan. For example, we know that cyclicality, the pattern in which turbocharger speed cycles up and down, is particularly relevant in determining the life of a turbocharger's rotating parts. Compressor and turbine wheels both have finite fatigue lives based on the three main cyclicality parameters: maximum speed, depth of speed cycles and the number of speed cycles. This is why we see much shorter turbocharger life on the engines in buses than in trucks, even though their maximum turbocharger speed may be identical.

That is not to say that we just have to accept this situation and can do nothing to extend the life of the bus engine's turbocharger. There are several approaches we can use to counter tougher cyclicality. We can:

- Use alternative wheel materials and manufacturing methods, moving from cast to semi-solid moulding (SSM) or machined-from-solid (MFS) compressor wheels
- Run the turbocharger more slowly by limiting its rating or altitude or both
- Work with the engine manufacturer to limit turbocharger speed in the particular application by careful driveline matching, gear-shift optimisation and torque-curve shaping.

Turbocharger bearing life is partly dependent on the number of engine shutdowns, especially if the engine is shut down very rapidly from a high load situation. Carbon is formed in the bearing clearances and around the turbocharger seals and

this can cause damage through abrasion or because oil flow becomes restricted. Rapid restart after rapid shutdown is even more damaging. This problem is most often seen in engines driving hydraulic or air compression equipment.

In contrast, turbochargers for on-highway automotive engines are almost never shutdown on load; it is even difficult to conceive a scenario where this could occur. However, even these turbochargers may well be subject to rapid shutdown and so their bearing specification has to take this into account. Modern turbocharger bearing design has made automotive turbochargers far more resistant to rapid shutdowns than was once the case. Water-cooled bearings in a well designed coolant circuit can almost completely eliminate the problem and are highly recommended for applications where rapid shutdowns are common.

It is turbocharger bearings under attack once again at the other end of the temperature spectrum, the cold start. Frequent start-ups from very cold conditions shorten turbocharger life because of the delay in oil reaching the bearings. Modern fuel-injection systems permit engines to fire very rapidly, so it is crucial that the oil pump, oil line and oil drain back routes are optimised to minimise the delay. The objective is to prevent the turbocharger spinning up to a high speed before oil flows through its bearings. As a guideline, oil should be at the bearings within three seconds of engine start-up. Helpfully, some engines have delays programmed into the management of their fuel injection systems, limiting engine fuelling until there is satisfactory oil pressure at the turbocharger.

Thanks to its extensive experience, Cummins Turbo Technologies has developed a large catalogue of applications, addressing their key characteristics, areas of risk and limitations of parameters such as speed and temperature. It allows us to assess most applications and determine how we can best meet customers' reliability and durability requirements. If we are looking at a completely new application, we identify its key operating characteristics and relate it to something similar we already have in our catalogue. From this, we will make recommendations on the in-service use of the product and we can often support this guidance with measurement and assessment in the field.

Designing and providing specific inspection and service routines can mitigate the difficulties of even the toughest duty cycles. In some applications, this is key to keeping expensive equipment operating consistently and reliably. Cummins Turbo Technologies' Service and Applications teams work together to provide this service option for our customers.

When an existing engine is put to use in a new and different application, our customers often expect us to reduce the operating performance envelope of the turbocharger because it was not designed with the new application in mind. In fact, very often we can extend some of the boundaries and so increase the turbocharger's performance. For example, standby generator sets are usually more highly rated than prime power units, simply because they are used only for relatively short periods.

We have developed a large catalogue of applications, addressing their key characteristics, areas of risk and limitations of parameters such as speed and temperature.

In an industry where base engines are being sold for an ever-widening variety of uses, the challenge for the turbocharger application engineer is to anticipate what these will bring for the turbocharger. We must understand how a new piece of equipment is to be used and consider how this will affect the operating envelope of the turbocharger. This often means close co-operation with the engine manufacturer, equipment manufacturer and the end user. Site visits are a regular part of our work and we can measure key parameters over extended periods, feeding the results into our analytical tools to see how life might be influenced. When giving guidance about the best turbocharger for that snow groomer working at 2,000 metres, our answers will have sound foundations.

The Axi-Radial Route to Very High Pressure Ratio Turbocharging

Written by Bahram Nikpour; Principal Engineer and Henry Tennant; Senior Technical Advisor

Conventional radial-flow compressors for automotive turbochargers are reaching a limit of about 5:1 pressure ratio in a single-stage. When realistic operating points within the map and application limits are observed, this means a useable pressure ratio of 4.2:1 at sea level.

Engines that need higher pressure ratios (PR) must use two-stage turbocharging systems but these bring challenges in terms of installation space, pipe connections and cost.

The axi-radial compressor was designed to avoid these issues by allowing a single turbocharger to reach a PR of up to 4.7:1 at sea level, with all normal stress limits observed. It comprises two compressor stages mounted on the same shaft and contained within a single compressor housing. This produces a turbocharger that sits within a conventional single turbocharger's outline, an obvious attraction to the engine designer working within the confines of the installation space.

The design is termed axi-radial because whereas most automotive turbochargers are of the radial type, with the gases entering the turbine and leaving the compressor radially ie. at right-angles to the shaft rotation, the extra compressor stage in this design is an axial compressor, with its output leaving in line with the shaft, feeding the usual main radial compressor. This axial-flow first stage achieves a small amount of pre-compression. A stator section is used to recover the static pressure and to set the flow direction for the following radial-flow stage. The system's overall PR is the product of multiplying the PR of the two compressor stages, ie:

$$PR_{Overall} = PR_{Axial} \times PR_{Radial}$$

So, for example, if the axial compressor has a peak PR of 1.25:1 and the radial's is 4.8:1, the combined PR would be 1.25 x 4.8 = 6:1. Additional axial stages could be added, as in multi-stage axial compressors used in gas turbines but this would require a completely redesigned bearing system.

One of the design challenges was that both compressor stages are attached to the same shaft and so, of course, have to run at the same speed. This means that optimising the design of the radial-flow compressor makes it more difficult to design the optimum axial stage. Two iterations of the axial and radial stages were analysed using Computational Fluid Dynamics (CFD) tools. The final design shown in Figure 1 uses a large axial hub diameter to increase the relative blade speed.

Another interesting problem was thought to be the relatively narrow operational range of the axial compressor in comparison to that of the radial stage. However, it was found during the course of this work

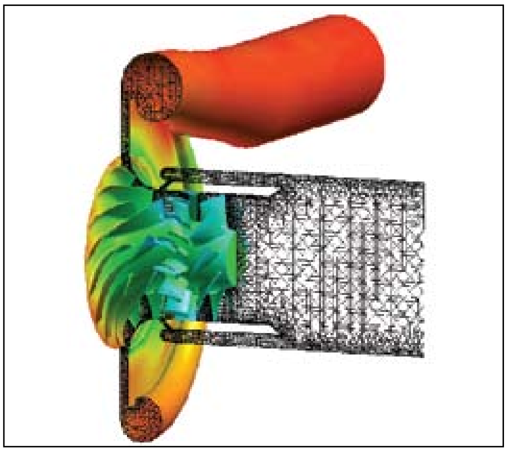


Fig 2 - Computational mesh

that the radial compressor imposes a stabilising influence on the axial compressor, making it possible to run well outside its individual flow range.

State-of-the-art computational tools were used to evaluate the combined axial and radial stage assembly, including the inlet Map Width Enhancement (MWE) channels, the diffuser and volute collector. Over six million computational elements were used in the analysis. Figure 2 shows a cross-sectional view of one computational mesh used during the design optimisation, showing how the details of the MWE were modelled.
Stereo lithography modelling was used to produce a rapid prototype plastic model of the rotor and stator, shown in Figure 3. The model was used to aid design of the compressor housing and stator mounting details.

Fig 3 - Rapid prototype plastic model

The axi-radial compressor map performance, together with that of one of our best single radial compressors, is shown in Figure 4. It illustrates the axi-radial compressor's capability to provide a PR some 20% higher at its maximum speed. At this point, the axial stage is contributing a PR of 1.25:1.

Careful design of the MWE system produces a flow range at a PR of 4:1 that is wider than the already excellent single radial compressor. The MWE details are the subject of a Cummins Turbo Technologies patent application.

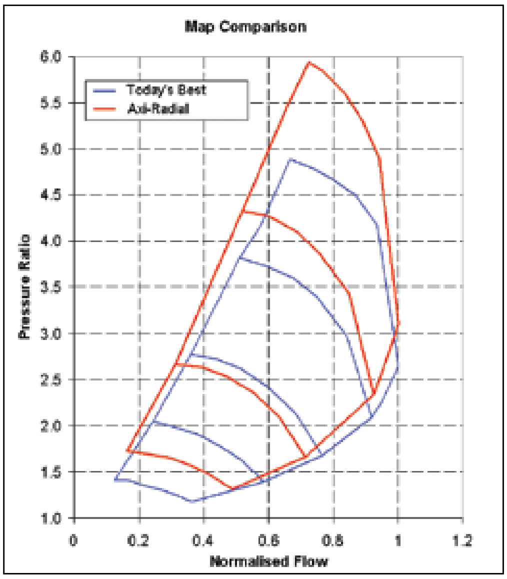


Fig 4 - Axi-radial compressor map

The additional axial compressor mass and overhang necessitated a considerable amount of bearing system and rotor dynamics analysis, including bearing stability tests. It was found that the standard bearing system could be retained. Modification of the journal bearing design allowed a stable system to be obtained over the whole operating range without any reduction of the normal maximum rotor speed.

Compressor noise was a concern with this design as there are more potential noise sources from the interactions between axial and radial wheels and the stator. It was felt also that the more complex MWE design might contribute to higher noise levels. Noise measurements made in our dedicated noise test facility enabled the contributions of the various noise sources to be evaluated and have shown that in fact the overall noise levels are not higher and are equivalent to conventional compressors.

State-of-the-art computational tools were used to evaluate the combined axial and radial stage assembly.

The compressor housing for test purposes was manufactured from cast-iron to provide stability at high pressures and the consequent high temperatures. Compressor outlet temperatures at a pressure ratio of 6:1 are approaching 300°C. A housing cast in steel could be used in production with the added benefit of significant weight reduction.

The axi-radial design demonstrates that it is possible to achieve a compact compressor stage that offers a significant pressure ratio improvement over a standard compressor, without losing compressor flow range. This compressor can allow retention of a single turbocharger for engines requiring higher pressure-ratios, avoiding the use of complex two-stage turbocharger installations.

The development of the axi-radial compressor was part of our contribution to a European Commission sponsored high Brake Mean Effective Pressure (BMEP) engine project entitled GREEN. Turbocharger samples were supplied to the engine partner and successfully evaluated on a test engine. Cummins Turbo Technologies acknowledges the financial support received from the European Commission during this project.

Fig 1 - Axi-radial compressor

ELV: Making a Material Difference

Written by Michael Voong; Senior Engineer, Materials Engineering

The End-of-Life Vehicles (ELV) Directive tackles the legacy of scrapped vehicles, starting with the materials that go into their components when they are manufactured.

Vehicles reaching the end of their lives generate millions of tonnes of waste in Europe each year. The European Directive 2000/53/EC, the ELV Directive, is intended to improve the management of scrap vehicles, ensuring they are dismantled and recycled in an environmentally friendly manner. By setting targets for recycling of vehicles and their components, it aims to reduce the amount of waste and minimise the environmental impact of scrapping vehicles. The ELV Directive also forces vehicle manufacturers to consider ease of recycling when they design and produce new vehicles. To this end, the directive sets out to reduce or ban the use of hazardous materials such as lead, cadmium, mercury, hexavalent chromium and other potential contaminants on new vehicles.

As well as the ELV Directive there are several other sets of regulations and initiatives that apply to the automotive industry and contribute towards controlling and minimising the use of hazardous materials. These include the Restriction of Hazardous Substances Directive (RoHS), the Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation (REACH) and the Global Automotive Declarable Substances List (GADSL).

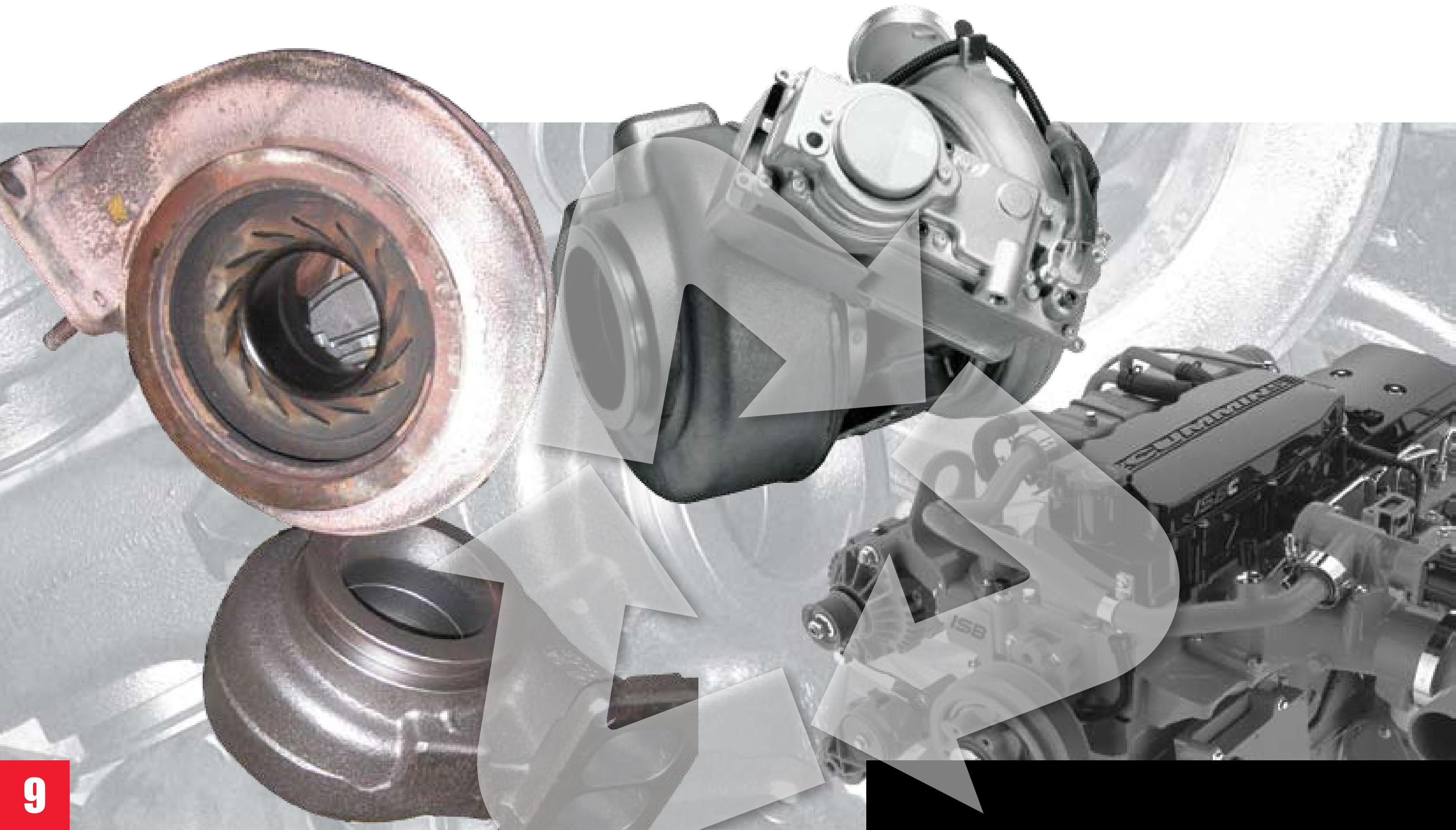
The ELV Directive was adopted by the European Parliament in September 2002 and first applied to new vehicles put on the market on or after 1 July 2002. Vehicles put on the EU market before 1 July 2002 were not covered until 1 January 2007. The directive is currently applicable only to vehicles in Categories M_1 and N_1:

- Category M1 – passenger vehicles with no more than eight passenger seats
- Category N1 – goods vehicles with a gross vehicle weight not exceeding 3.5 tonnes.

As Holset turbochargers for Europe are for heavier vehicles, the ELV Directive does not apply directly to Cummins Turbo Technologies and its products. Nevertheless, as a global company that takes its impact on the environment very seriously, we are constantly evaluating our products to ensure that such requirements and any future requirements are met.

Hexavalent chromium was widely used as a corrosion-resistant protective coating on metal parts. However, it has been identified as a human carcinogen (capable of causing cancer) and if not disposed of correctly may contaminate land and water. Due to these health and environmental dangers the ELV Directive stipulates that as of 1 July 2007 hexavalent chromium must be removed from all components in new vehicles. Cummins Turbo Technologies worked extensively to remove hexavalent chromium from its products worldwide ahead of this date.

Cummins Turbo Technologies is also testing and evaluating lead-free alternatives for turbocharger materials and components. For example, although the ELV Directive allows a nominal amount of lead, since October 2006 Cummins Turbo Technologies has completely eradicated lead as an alloying element in our free-cutting steel. We have already made major strides towards removing lead from our products and plan to launch the first entirely lead-free Holset turbocharger before 2013.



Build in Poka-Yoke to Eliminate Mistakes

Written by Michael Daley; Manufacturing Program Manager

Cummins Turbo Technologies' world-class Palmetto plant is in Charleston, South Carolina. Covering 120,000 sq ft /11,150 m², it not only machines turbocharger components but also has two highly automated assembly lines and two hot-test cells.

Representatives of suppliers and customers were among those who participated in design process workshops set up to review previous failure modes and identify the potential for errors in each step of the manufacturing process. Potential Failure Modes Effects Analysis (PFMEA) has been used to develop and build manufacturing systems to produce high quality turbochargers. Poka-Yoke, the Japanese philosophy for designing operations in such a way to prevent mistakes being made, has been applied throughout the manufacturing process at Palmetto. Here are a couple of examples.

Machining

State-of-the-art Computer Numerically Controlled (CNC) machinery and highly automated two-plane balancing equipment are used for machining key turbocharger components such as shaft and wheels, and impellers. These are the heart of a turbocharger and require micron-level tolerances to survive in the turbocharger's harsh environment. To put that into perspective, a micron is one millionth of a metre: a dust particle is approximately four microns.

Sophisticated measuring equipment is used throughout the process, including laser based non-contact gauges, Instron tensile testers, Rockwell hardness testers, air gauges, surface measuring equipment, optical comparators and a Co-ordinate Measuring Machine (CMM). Poka-Yoke and Statistical Process Control (SPC) methods are applied throughout the machining process to either prevent or detect defects. For example, Poka-Yoke is used for two dimensional marking for traceability/part number fail-safing, thread and speed indicator presence verification and signature analysis on induction hardening and friction welding process parameters.

Assembly

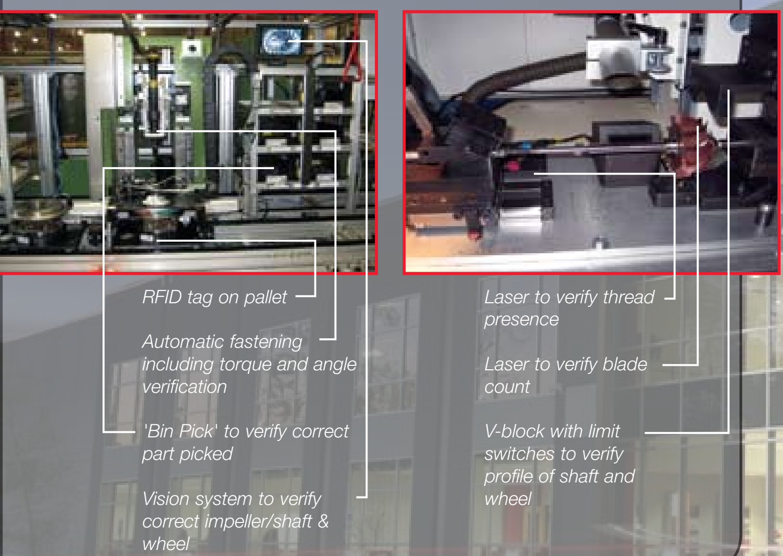
Palmetto's two assembly lines are controlled by Programmable Logic Controllers (PLC) and linked to a computerised assembly management system. Each turbocharger is given a unique serial number at the beginning of assembly and assigned to an assembly pallet using Radio Frequency Identification (RFID) tags. Displays at each workstation instruct staff what model to build and provide the appropriate work instructions. Key components are scanned and process information is stored about each turbocharger for traceability and data analysis. If a turbocharger fails any of the in-process verification tests, its serial number is flagged and assembly cannot continue until the turbocharger is removed from the assembly line for analysis.

Poka-Yoke is used extensively to ensure assembly is correct, including:

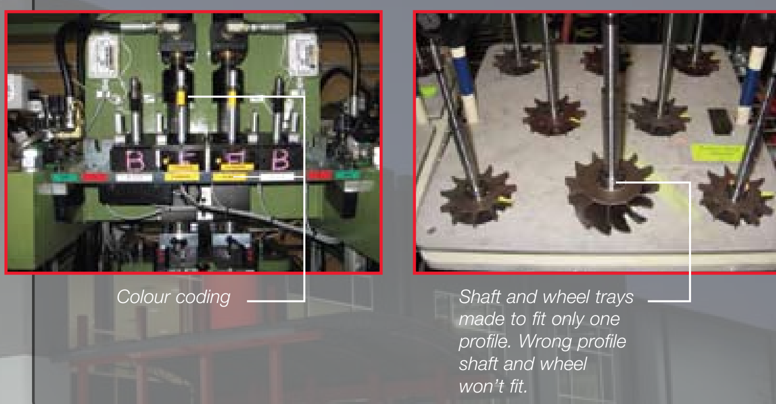
- Barcode scanning of components for part number verification and tracing
- Leak testing
- Eddy current analysis to verify correct assembly
- Pick-to-light systems for accurate component selection
- 100% on-line robotic inspection to verify customer mounting-flanges are orientated correctly.

These are just some examples of how Poke-Yoke enables Cummins Turbo Technologies, Palmetto to achieve improved operational effectiveness. Other fail-safing techniques are used at all our worldwide manufacturing facilities to ensure a high quality product.

High Technology Poka-Yoke



Low Technology Poka-Yoke



Planning for Service and Serviceability

Written by Dave Antcliffe; Service Engineering Manager, European Accounts

Long before a turbocharger gets anywhere near its end-user, the Service Engineering department has a major input into the design, development and release of the product into the market.

For example, let us assume that a vehicle develops a problem that appears to stem from its turbocharger. How does a technician who has to repair the vehicle go about tracing the fault and diagnosing its cause? The smart way is to use the fault-finding charts provided jointly by Cummins Turbo Technologies and the original equipment manufacturer (OEM). These charts list the symptoms of turbocharger problems, guide the technician to the root causes and outline how to tackle them.

The Service Engineering team will have drawn up this guidance, often starting with the turbocharger's Failure Mode and Effects Analysis (FMEA) that was generated by the design team. Considering all the possible faults that could arise with a turbocharger, we then extend the thought process to see what effects they would have on the rest of the engine and on the vehicle's performance. Working with our customer, the OEM, we are able to include the fault codes generated and stored by an engine's electronic control unit. Having started with potential faults and arrived at their symptoms, we then reverse this to create a chart for the technician who is faced with symptoms and needs to get back to the fault and repair it.

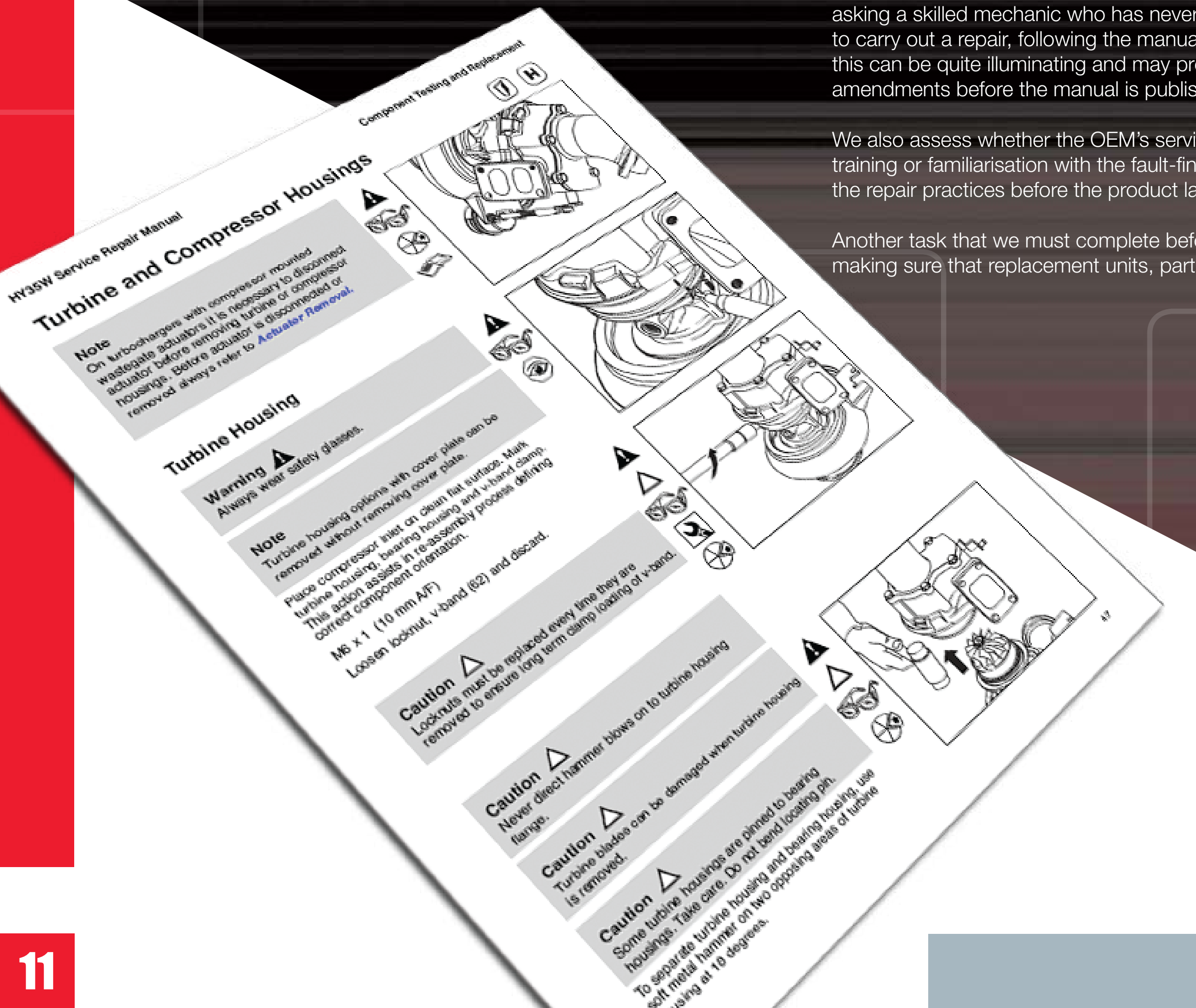
These fault-finding charts are included in our workshop manuals, also prepared by the Service Engineering team. These manuals provide guidance on how to carry out recommended repair practices. Most faults early in the life of a turbocharger are covered by warranty and in these circumstances often the solution is to replace the product. However, whenever repair or maintenance is the correct course of action we have to spell out what should and should not be attempted. We aim to support correct repair practices and prevent those that potentially are too complex or have a high risk of subsequent failure.

As new models are introduced, the Service Engineering team reviews existing manuals and identifies what revisions are needed to incorporate the new designs. These manuals are prepared in conjunction with Aftermarket Engineering and are published on the Cummins Turbo Technologies website and made available to the OEM for its own manuals.

Preparation of the manual starts with a definition of detailed activities. Then we take photographs of the repair processes and use these to create line drawings, supplemented with original component drawings. The accompanying text and layout is produced by a technical author and software house to maintain consistency of content and layout. Finally, we test the manual by asking a skilled mechanic who has never seen the turbocharger to carry out a repair, following the manual's guidance. Watching this can be quite illuminating and may prompt us to make some amendments before the manual is published.

We also assess whether the OEM's service technicians need any training or familiarisation with the fault-finding process or any of the repair practices before the product launch.

Another task that we must complete before the launch is making sure that replacement units, parts and repair kits are



HY35W Service Repair Manual

Component Testing and Replacement

Turbine and Compressor Housings

Note
On turbochargers with compressor mounted wastegate actuators it is necessary to disconnect actuator before removing turbine or compressor housings. Before actuator is disconnected or removed always refer to Actuator Removal.

Turbine Housing

Warning
Always wear safety glasses.

Note
Turbine housing options with cover plate can be removed without removing cover plate.

Place compressor inlet on clean flat surface. Mark turbine housing, bearing housing and v-band clamp. This action assists in re-assembly process defining correct component orientation.

M6 x 1 (10 mm A/F)
Loosen locknut, v-band (62) and discard.

Caution
Locknuts must be replaced every time they are removed to ensure long term clamp loading of v-band.

Caution
Never direct hammer blows on to turbine housing flange.

Caution
Turbine blades can be damaged when turbine housing is removed.

Caution
Some turbine housings are pinned to bearing housings. Take care. Do not bend locating pin.

To separate turbine housing and bearing housing, use soft metal hammer on two opposing areas of turbine housing at 10 degrees.

readily available. It is essential that we support the OEM service activities as soon as the product is introduced and ensure that any parts or repair kits needed for out-of-warranty work are available by the time the warranty period has expired.

An essential aspect of the design process is what we call 'design for serviceability'. Simple service instructions such as 'undo' or 'remove' must be able to be accomplished without anguish, so we work to ensure that our products can be disassembled and reassembled easily. Our service policy defines that, ideally, this process should be possible using only tools available within a normally equipped workshop. Occasionally, this may not be possible and we have to design and supply special equipment for a particular task.

Another part of our philosophy is 'design for remanufacture'. After the first life of a turbocharger, it may be eligible for remanufacturing. This allows turbochargers, to original specifications, to be offered into the replacement market at a lower cost. There are also environmental benefits of re-using instead of scrapping. Feedback on new turbocharger features is invited from the remanufacturing team as part of the design review process.

Setting and working towards all these aims is not enough: we have to make sure that we achieve them. In 2007, we carried out a Six Sigma process redesign within the Aftermarket Engineering department, with Service Engineering input. This led us to create a checklist that we follow for each project.

Thorough processes, together with a review and check system are designed to ensure that nothing slips through the net.

A cross-functional Aftermarket Value Package Introduction (VPI) team reviews each phase of any new project. In the early stages of the project the team works through the checklist gathering information about the product:

- Potential market
- Where the product will be made
- The need for new or revised manuals
- Customer training requirements
- Design for serviceability and remanufacturing.

Service repair practices and supporting spare parts policies are also defined. As the project gets closer to production, initial answers are reviewed and additional checklist questions are added, particularly with regard to part numbers and availability of parts and repair kits.

Thorough processes, together with a review and check system are designed to ensure that nothing slips through the net. These lay the foundations for the very best service support for our turbochargers and hence for our customers.

Net Promoter® Score: Do We Have Satisfied Customers or Loyal Customers?

Written by James Moorhouse; Marketing Co-ordinator

It was in 2007 that the Cummins Customer Support Excellence Operating Committee agreed that it would adopt a company wide metric to measure customer loyalty, reinforcing the objective 'to become the first choice for customers'.

But how do you create customer loyalty and how do you measure it?

Those were the questions posed to four Cummins business units, including Cummins Turbo Technologies, who were invited to participate in the pilot of a new customer loyalty measure known as Net Promoter Score (NPS).

For almost 10 years, Cummins Turbo Technologies has used a formal system called the Customer Relationship Review (CRR) to measure customer satisfaction. However, research has proved that satisfied customers are not always loyal customers. The research suggests that the willingness to recommend a person or a company to someone else is a better indicator of loyalty because this puts one's own credibility and reputation on the line.

It is the 'customers likelihood to recommend' that is the underlying principle of the NPS, a simple way of measuring loyalty developed by Fred Reichheld, a top USA based management consultant in conjunction with Satmetrix Systems Inc. NPS aims to gauge a company's performance as seen through the eyes of its customers.

"If growth is what you're after, you won't learn much from complex measurements of customer satisfaction or retention. You simply need to know what your customers tell their friends" Reichheld, 2003[1].

In 2008, Cummins Turbo Technologies commissioned a market research agency to conduct an NPS survey among a cross-section of its customers, focused on the simple question, "How likely is it that you would recommend Cummins Turbo Technologies to a friend or colleague?" This, according to Reichheld's research, is the single most important question that should be asked when assessing customer loyalty. In the Cummins Turbo Technologies survey this key question was followed by various others regarding the different areas of the business, allowing customers to focus on specific concerns that they may have.

Following the survey, a workshop involving 23 managers across 14 functions was set up to analyse customer feedback and as a result many Customer Focused Six Sigma (CFSS) projects have been identified. A project has now been launched to evaluate the success of the NPS pilot and to look at how the technique can be developed within Cummins Turbo Technologies moving forward into 2009. The objective is to ensure that any customer issues are picked up and acted upon promptly, driving up customer loyalty.

In short, a better understanding of its customers will give Cummins Turbo Technologies new ways of developing its business to meet customers' needs, providing the best-in-class product performance, quality and service.

How likely is it that you would recommend Cummins Turbo Technologies to a friend or colleague?

[1]Reichheld, F F., (2003), The One Number You Need to Grow, Harvard Business Review, p.1-10, Dec 2003.
Net Promoter is a registered trade mark of Fred Reichheld, Satmetrix and Bain and Company.

Showcasing
Our Latest Technology

Written by Tim Eady; Marketing Co-ordinator

Cummins Turbo Technologies has exhibited at four major automotive events this summer, promoting its industry-leading technology and expertise.

Goodwood Festival of Speed - UK

Organisers of the annual Goodwood Festival of Speed say the 2008 event was the best one yet, more action-packed than ever for the 140,000 plus spectators. Each year they flock to this celebration of motor sport held over three days in June at the picturesque Goodwood near Chichester, West Sussex. Just a week after he drove to victory in the British Grand Prix, Formula One World Champion Lewis Hamilton was given a rapturous reception by the crowd when he appeared on the balcony of Goodwood House.

Cummins Turbo Technologies' display at Goodwood included the new axial turbocompounding unit, the Holset HP841 with a Holset HX55 turbocharger. The Dodge Ram 2500 pickup with a Cummins 6.7 litre turbo diesel engine and Holset HE351Ve turbocharger were guaranteed to draw visitors to the stand, as was the huge 6.5 tonne, 60 litre, 2700hp Cummins QSK60 engine featuring an impressive 4 Holset HX82 turbochargers.

Automechanika - Germany

This was the 20th anniversary of the famous automotive components show, Automechanika. Held every two years in Frankfurt, Germany, Automechanika is widely regarded as one of the most important venues for key decision-makers in the automotive business. This year's event attracted over 4,600 exhibitors and 166,000 trade visitors from 146 nations.

Automechanika's theme was global warming and its impact on the automotive aftermarket, looking specifically at how technology can cut exhaust emissions, particularly carbon dioxide (CO_2). In keeping with this, Cummins Turbo Technologies demonstrated how Holset turbochargers reduce emissions and pollution across a diverse range of applications, whilst delivering improved vehicle performance. Our stand promoted the message that 'the right technology matters' and launched the new, multi-language 'Insist on Genuine Holset Turbochargers' DVD to highlight the hidden dangers of counterfeit turbochargers. Cummins Turbo Technologies also hosted a meal in Frankfurt for its authorised distributors where the top 41 received awards to recognise their Gold status.

ADS International Convention - USA

The theme of this year's convention of the Association of Diesel Specialists (ADS) in Las Vegas, Nevada was 'Betting on Diesel,' looking at the fuel choice facing USA buyers of cars and trucks. The presentations and discussions are invaluable in helping to understand the future direction of the market. Cummins Turbo Technologies was one of 140 exhibitors at the convention, which was attended by over 600 delegates from 34 countries.

IAA Commercial Vehicles Show – Germany

Everything about the biennial IAA Commercial Vehicles Show in Hannover is huge and this year's, the 62nd, held during the last week of September, was bigger than ever. The number of exhibitors rose to 2,084, up by 34% on the 2006 show. Visitor attendance was 12% up to nearly 300,000. This is a truly international event, with exhibitors from 48 countries, over half the exhibitors were from outside Germany. Many of the visitors had travelled even further, coming from 110 countries. It all adds up to a record breaking show.

The main focus at Hannover was increasing transport efficiency and climate protection, both of them timely themes for an industry working to ever tougher environmental standards in a particularly difficult financial and economic climate in many parts of the world right now.

Successfully projecting the Cummins 'one company' image, the Hannover stand was shared between Turbo Technologies, the Engine Business Unit, Filtration and Emissions Solutions. The show was a great success, with Cummins Engine Business Unit launching its new 2.8 and 3.8 litre ISF engines featuring the Holset HE221W. This was supported by displays of turbochargers, filtration and emissions control products. We look forward to continuing the success of our joint representation at shows into 2009.

Goodwood

Automechanika

ADS

IAA

Turbo
Technologies

Our Goals

Cummins Turbo Technologies places the utmost importance on achieving high levels of product and service quality.

Our people are the single most valuable asset we have to ensure we meet your requirements. Through structured training development programmes we encourage our employees to spend approximately 5% of their working time in training and personal development.

Our operations worldwide are certified to TS16949 quality standard and we welcome suggestions as to how we can further improve our performance to meet your needs.

We take our environmental obligations seriously and all our worldwide sites have achieved ISO14001. Our products have an important part to play in helping to improve engine emissions.

Our goal is to provide the lowest total cost solution for your turbocharging needs.

Part Number: 3766118 Edition 11 Ref: AS/OR Effect Date: 11:08