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.

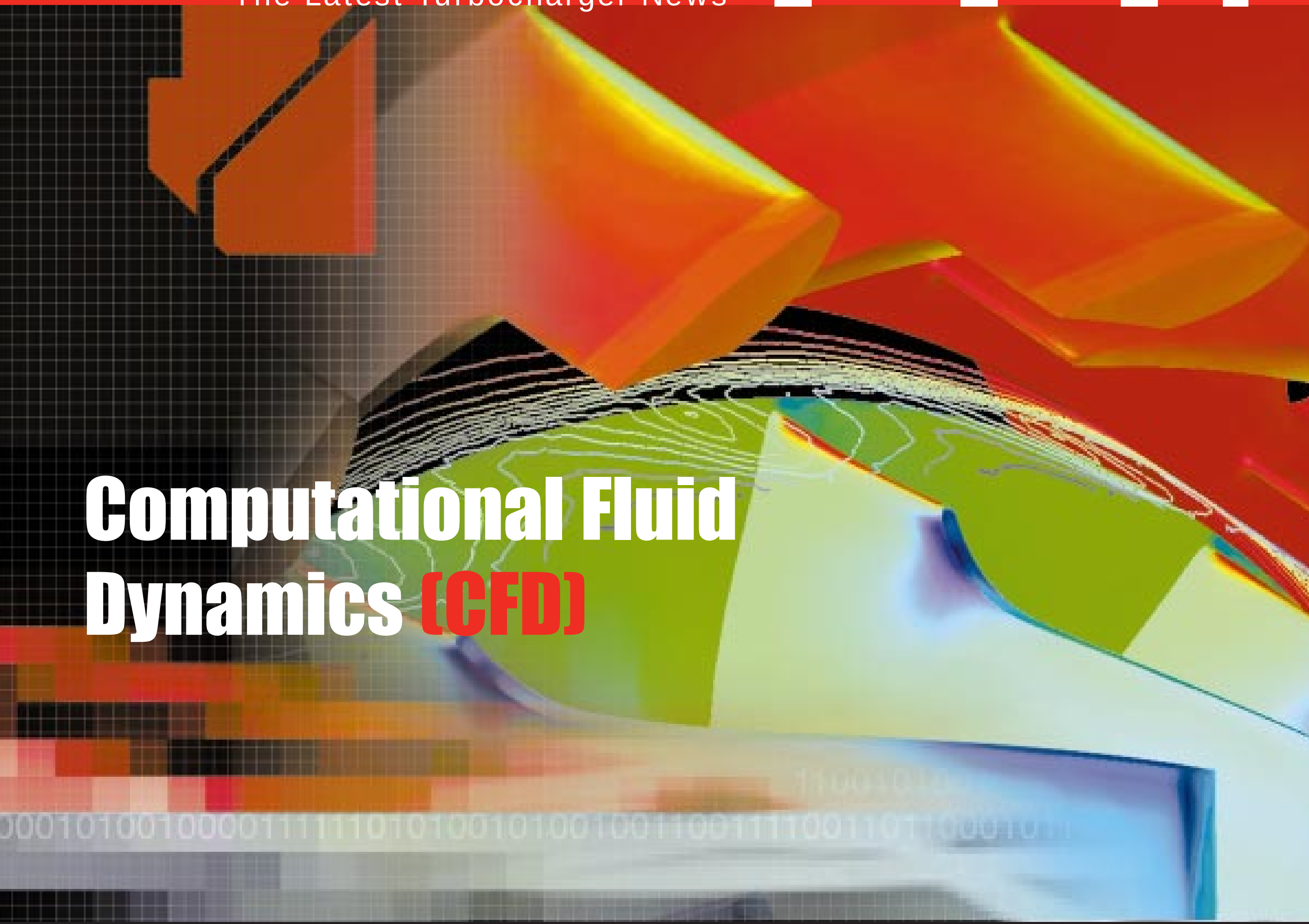
Our goal is to provide the lowest total cost solution for your turbocharging needs.

Part No. 3766118 Issue 6 Ref: AJS/OR

Cummins Turbo Technologies

HTi

The Latest Turbocharger News



Computational Fluid Dynamics (CFD)

EDITION 6:

Comments from the Leadership Team

Paul Ibbotson

You will instantly recognise a change to the look of this publication and indeed the look of many of our entities worldwide.

Cummins is moving to a global brand strategy that will create one global brand. This involves reducing the many existing subsidiary and organisational brands within Cummins to communicate as one company with one voice to the market. This also involves Holset changing our name to Cummins Turbo Technologies, to align ourselves more closely to the Cummins family.

There is significant value in this new strategy. It will build a much stronger global brand, portraying Cummins as a company that offers a range of products and services; not just engines, not just turbochargers or generators or filters, but a company that can meet all our customers' needs relating to power across the globe.

Providing clear direction about brand strategy enhances a company's ability to communicate its identity both internally and externally. As our customer base around the globe continues to grow, this gives Holset the opportunity to increase market share and also help with the recruitment and retention of the best quality of people. Coming together as one under the Cummins name will make us a stronger company and better position us for continued success in a global economy.

However, we will not lose the Holset name; the Holset Turbochargers brand will remain as our product brand and will continue to be used on our products and throughout our aftermarket. The change affects our corporate identity only; we are creating a distinction between the company we work for; Cummins and the products we sell; Holset.

Holset has been part of the Cummins family for over 30 years. Cummins and Holset share the same vision; the same mission statements. We are both committed to quality products and believe in exceeding customer expectations in all that we do. Both Cummins and Holset value their workforce and boast equality and diversity as a part of their culture. Together, under the Cummins name we will continue our commitment to operate with integrity and do what is right. This branding change is simply another step in Cummins evolution as a global power company, to guarantee long-lasting success in a highly competitive environment.

This branding change will be communicated to shareholders, customers and suppliers on 9 May 2006 at the Cummins Annual General Meeting. Throughout the remainder of the year, we will be taking steps to integrate our corporate identity with the new strategy. The changes apply to all of Holset's wholly-owned entities. Separate discussions are underway with our joint venture partners and details will be made available at a later date.

These are exciting and challenging times. In the end, we will all be proud of what has been accomplished and will have a greater sense that we are a family – One Company, with One Voice and One Focus for the benefit of ourselves and all our stakeholders.

Paul Ibbotson
Managing Director

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

HTi is produced using an environmentally approved printing process and is printed on fully recyclable and biodegradable paper.

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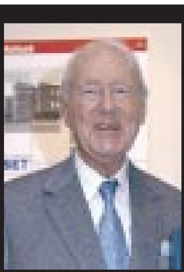
The History of Holset

Written by Sara Walls, Communications Co-ordinator

Over the last fifty years, Holset has faced many changes and challenges, none more recent than the latest announcement of realigning Holset with the Cummins brand. HTi took a trip down memory lane to speak to the founder of Holset, Paul Croset and one of its earliest Managing Director's, Ron Hesselden, to hear about their journey in creating what Holset means to us today.



Paul Croset O.B.E.

Paul Croset pursued an engineering career largely as a result of his father, Louis Croset, who was Chief Diesel Engine Designer at Davey Paxman & Co in Colchester. After an apprenticeship at Crossley Premier Gas & Oil Engine Company in Sandiacre, Paul joined Davey Paxman to advise on torsional analysis.

At that time, Louis Croset was a consultant to W C Holmes and designed a flexible coupling that was sought after by Dan Henshaw, Chairman of W C Holmes. Brian Holmes (grandson of the founder W C Holmes) was responsible for establishing the new flexible coupling department, which Paul headed from December 1948. Paul convinced Brian Holmes that the new venture must include vibration dampers; the success of which he would personally guarantee.

Ron Hesselden

Ron started his apprenticeship at a small machine tool company called Carter and Wrights and later moved to David Brown Tractors in Huddersfield. Ron's early mentor was Geoff Moorhouse, father of Holset's late Managing Director, David Moorhouse.

In January 1946, Ron moved to English Electric in Stafford and to Rowntrees of York where he worked on the design of the Polo Mint machinery.

In September 1949, Ron was recruited by Paul for the design of couplings and dampers. What to call the new business was soon on the agenda. Paul did not like the idea of calling the company Croset so Brian Holmes suggested using the first three letters of his family name, HOL and the last three letters of Paul's, SET; hence HOLSET. The business then traded as the Holset Division of W C Holmes until the Holset Engineering Co Ltd was formed in March 1952.

For many years, nearly all the large industrial, rail traction and marine diesel engine manufacturers benefited from the advantages of turbocharging. The trend was now to try to make a small low cost turbocharger suitable for the heavy duty automotive sector.

In 1954 a licence was taken from Dr Alfred Büchi (the inventor of turbocharging) to manufacture his design and for Holset to gain experience in turbo-machinery. By 1957, Schwitzer Corporation of Indianapolis had developed a small light weight turbocharger and a close association with Schwitzer followed.

Holset was able to add the key household names of European heavy-duty engine manufacturers to its customer base and over the years this list has continued to grow until today, where every major OEM is a customer and Holset is acknowledged as the leading manufacturer of heavy-duty automotive turbochargers.

Cummins' Purchase of Holset from Hanson Trust on 15 November 1973

Paul Croset resigned as a Director of Hanson Trust, which had owned Holset for a short while and was welcomed back as Chairman of Holset. Paul and Ron Hesselden, who was Managing Director of Holset, met with the Cummins Engine Company and were impressed with its outstanding leaders; J Irwin Miller, Chairman; Henry B Schacht, President; James A Henderson and John Hackett among them. Clearly they had a genuine care for their employees, the local community and their customers.

When Cummins visited Holset, they were equally impressed with Holset's knowledge of turbocharger technology and it was clear to them that Holset's technology was more advanced than their own. This was not easy for some in Cummins to accept because they had their own turbocharger department but Holset and Cummins decided to join together and the rest, so they say, is history…

HTi asked Paul Croset and Ron Hesselden for their views on moving forward and realigning ourselves with the Cummins brand.

"I fully support the change of name from Holset to Cummins Turbo Technologies," Paul says. "Holset is owned by Cummins and this change is in line with the corporate philosophy of total transparency."

"Company and product branding has become increasingly important as our market place is now global," Paul continues. "The financial communities, shareholders and investors around the world need to have a clear vision of the company and its products. It is easy to forget that there would be no company without shareholders."

As for the future of the Holset turbocharger, Paul confirms that this is assured because it is an integral part of the engine combustion process. The turbocharger also plays an important role in meeting emission standards.

Ron adds "Holset has been wholly owned by Cummins for over 30 years and both companies operate to the highest ethical standards in their business practices."

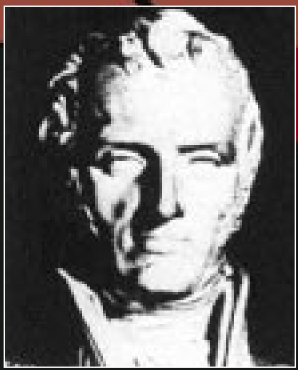
"I understand the Holset Turbochargers logo will remain and therefore I do not believe the change in name will affect the company in any way," Ron says. "If there are benefits to be had by the change in name, then the whole Cummins family benefit. My firm view is 'Go for it!' The most important factor is what the company stands for in its relationship with customers, employees, suppliers and the local community."

Holset has been wholly owned by Cummins for over 30 years and both companies operate to the highest ethical standards in their business practices

Ron remarked "I am certain the future is bright. The company's standing has never been higher; a world leader in its field with the highest standards in all aspects of its global business. I am so proud of the company I helped to build. I have no doubt that the decision to join Cummins has been the right one for the company, now and in the future."

Computational Fluid Dynamics (CFD) - Past, Present & Future

Written by Richard Evans, Principal Engineer - Aerodynamics Group



Claude Louis Navier

George Stokes

It is nearly 200 years since Claude-Louis Navier and George Stokes independently derived the mathematical equations that now jointly bear their names. We are nevertheless still using them today to analyse the behaviour of liquids and gases in motion.

Engineers in the 21st Century are more familiar with the technique of computational fluid dynamics (CFD), though its principles are based squarely on the Navier-Stokes equations. The application of CFD is rapidly expanding, as researchers endeavour to simulate fluid flows in a host of different aerodynamic, engineering and even medical environments. From supersonic aircraft and missiles, Formula One racing cars, through rivers and dams to lung and blood vessel functions, CFD methodologies can be and are applied. The air and gas flow through an internal combustion engine is a typical example.

Cummins Turbo Technologies has been using CFD as a viable industrial tool since it first evolved out of university research departments and government agencies in the late 1980s. A long and fruitful collaboration with the University of Cambridge has enabled Cummins Turbo Technologies to stay at the cutting edge of CFD development and application in the specialist field of turbomachinery simulation.

In many ways, CFD is now quite a mature technology. The algorithms, models and techniques used to solve the governing equations have not changed significantly in the last 30 years. The fluid volume is broken down into thousands or millions of volumetric cells and the equations are solved by a computer program iteratively over all the cells until the changes from one iteration to the next are acceptably small, in what is referred to as ‘convergence’. In general, the greater the number of cells, the more accurate the solution, though using more cells inevitably takes a longer time.

As time to convergence is essentially a function of computer speed, CFD has benefited spectacularly from the exponential increases in processor power seen in the last decade. Today, any company involved in fluids engineering will employ CFD at some level. The huge growth in numbers of users and the now wide acceptance that CFD provides a genuine third way, between pure theory and experimental testing, is attributable to ever greater and more complex simulations of a kind that would have been impossible five or ten years ago.

Cummins Turbo Technologies has seen this expansion in CFD applications at first hand. In 1990 the simulation of the flow through a single passage of a turbocharger compressor wheel at a single operating point, modelled with 53,000 cells, took typically four to five days. In the same amount of computer time today, we could predict the entire performance map of a compressor stage, modelling the inlet, wheel, any casing treatments and the compressor cover in their entirety with a mesh of about 4 million cells. Such CFD predictions are extensively validated against test data, giving us a very high confidence in the accuracy of our results.

A key factor enabling our CFD function to perform these large simulations in an acceptable time scale, is the use of a parallel cluster: a collection of PCs running a linux operating system and linked by a high-speed network. Each PC is assigned a portion of the fluid domain to solve, known as ‘domain decomposition’ and is run in parallel with all the other PCs, communicating with each other at the end of every solver iteration. At the end of the run the portions are recombined into a single domain. We currently have 32 processors in the cluster so that theoretically, we can achieve a result 32 times faster than running on a single processor. In practice the time saving achieved is slightly less than this due to the inter PC communication involved at the end of every iteration.

The reduction in time-to-solution, from days to hours, has also meant a large increase in the range of problems that we can now analyse. Although many CFD runs are still concerned with the prediction of aerodynamic performance, we now regularly use the simulations to help predict thermal and aero-mechanical loading. This is increasing our knowledge of high cycle fatigue in turbine wheels. Leakage flows through seals and piston rings and the optimisation of coolant flow in water-cooled components are further examples of CFD simulations. We have also investigated such diverse problems as the generation of aero-acoustic noise at a turbocharger’s compressor inlet, the behaviour of oil mist particles from closed crankcase ventilation applications and the implications of changes to the oil feed in bearings systems.

When any CFD computer run is completed, a vast amount of data is returned to the results file. The flow variables, relating to pressure, temperature and velocity, for every single point in the computational mesh are available for interrogation. It is a key strength of CFD over physical testing that the entire flow field is opened up to the researcher.

Cummins Turbo Technologies employs some sophisticated post-processing software to help make sense of the huge amount of information available. Thus not only can standard information such as efficiency or mass flow rate be calculated, the engineer can also see the flow field in motion and understand why performance may have changed. Regions where the fluid flow is performing poorly, or not as intended, can be quickly identified and assessed for their effect on overall performance.

Using CFD also gives engineers more freedom to explore 'what-if' questions. By simply trying things out in the simulation environment, the effects of different physical flow related geometric turbocharger features; notably slots, vanes, fences, ridges and by-passes, can be investigated, interpreted and understood. It can be undertaken without having to consider manufacturing and assembly constraints at the very early stages of design. If such innovations show promise, they can then be matured into production strength solutions with due consideration for mechanical, installation, market and cost issues, amongst others.

This increase in understanding with every CFD simulation brings a valuable reduction in the old 'cut and try' methods of development. Of course, physical testing will always be used to verify designs, but the ultimate aim is to reduce the amount of trial and error testing by having already run through most of the design cycle in the computational environment.

Future development of CFD capability will probably advance on two fronts, in both of which Cummins Turbo Technologies is actively involved. Firstly, we can expect closer integration of CFD with computer aided design (CAD) systems and mechanical finite element analyses. At present, each design or analysis tool has

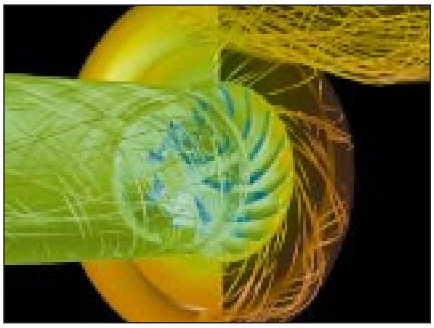
Using CFD also gives engineers more freedom to explore 'what-if' questions

its own representation of a particular geometry.
For example, if changes are made to the CAD model, they are not automatically incorporated into the fluids solver or stress prediction codes. The user must manually change or update the computer models to allow their analysis in each different package.

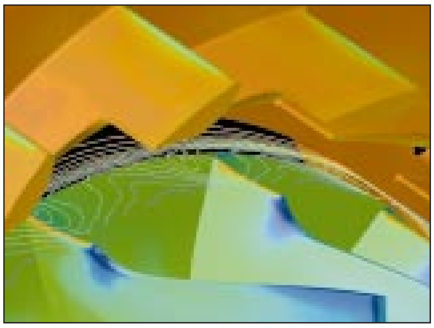
Fortunately, Cummins Turbo Technologies is closely aligned with ANSYS-CFX, the commercial code vendors who are working towards the integration of design and analysis tools. Their aim is to have each component described by one central geometry model that can be used by all analysis programs. Furthermore, the results from one code can then be passed seamlessly to another, enabling fluid structure interaction to be modelled where aerodynamic loads twist or bend a component, which in turn changes the flow field around it.

Another key advance is in optimisation, for instance, allowing the CFD code to automatically modify blade geometry, so as to meet a specified performance or efficiency target but under specified constraints (for example, blade thickness). Optimisation generally demands hundreds of quick computer runs, in order for the optimiser algorithm to understand what changes give what effects and then to move towards an optimum solution for a given target but without violating the defined constraints. It also demands careful management of the parameter space (ie how many different things the optimiser can change and by how much). Too many parameters implies a huge number of runs in order to find an optimum; too few and the design will be over constrained.

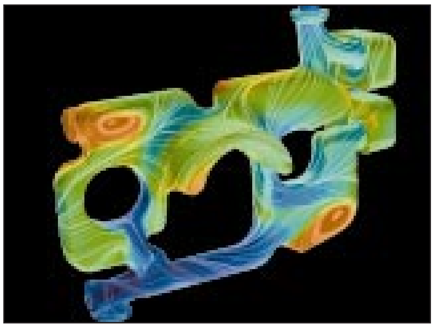
Cummins Turbo Technologies intends to remain at the forefront of CFD for turbochargers. This will allow us to fully exploit the potential of this technology to deliver greater performance, durability and quality throughout our product range.



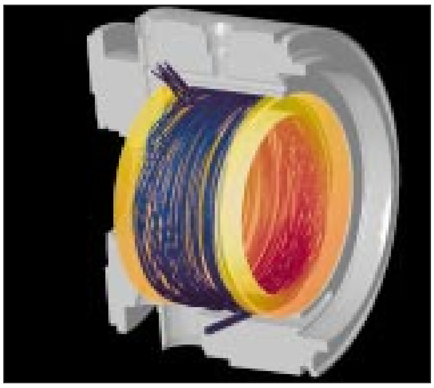
CFD simulation of full compressor stage including MWE casing treatment. The streamlines and surfaces are coloured by air density.



Detail of a VGT™ turbine stage. The contour surface shows the variation in the pressure field between the stator vanes and the rotor.



Coolant flow through a VGT™ bearing housing cooling cavity. The colouring indicates surface temperature, which is highest in areas where the coolant is recirculating.



Surface temperatures and flow pattern for the coolant of an electrical assist turbocharger (pp 7-8, HTi edition 5).

India and Brazil bring new business

Written by Rui Barbieri Filha, Engineering Supervisor, Ricardo Souza, Applications Engineer and KP Dilshad, Account Leader Sales and Marketing

Cummins Turbo Technologies has secured two important new OE customers. In India, Tata Holset has won a contract to supply turbocharger equipment to Force Motors, the latest contender in the increasingly competitive Indian heavy commercial vehicle market. In Brazil, Cummins Turbo Technologies has been working closely with Volkswagen to bring its new Constellation range of trucks to the market.

Force Motors has formed a joint venture (JV) with MAN from Germany to build a range of trucks in the 16 to 50 tonne weight category. The collaboration is set to be further extended with the signing of a letter of intent with MAN for a manufacturing programme at Force Motors' Akurdi plant near Pune. The planned JV is intended to open up markets outside Europe for MAN with trucks being produced for markets throughout Asia. To date, Force Motors' production activity has been confined to the light commercial vehicle, multi-utility vehicle, three-wheeler and tractor segments. The addition of heavy commercial vehicles to its portfolio represents a major step forward for the company.

Image supplied courtesy of Force Motors

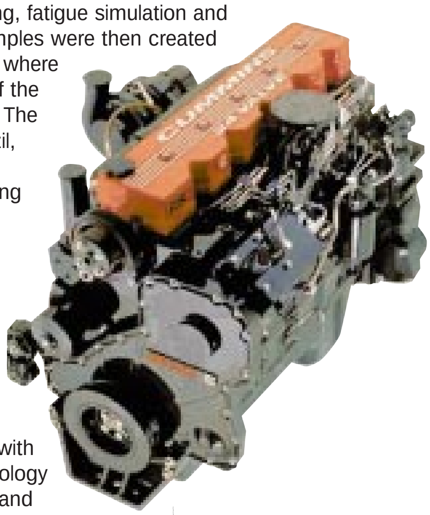
The first prototype 40 tonne vehicle was rolled out from Force Motors' new Akurdi truck research and development centre in August last year. The first engines were supplied from MAN's Nuremberg plant in Germany, equipped with Holset HX40W turbochargers. Local component sourcing plans for the engine include supply of turbochargers, starting later this year, from Tata Holset. As the heavy-duty truck market grows in India, Tata Holset will support Force Motors on several new turbocharger applications.

On the other side of the world, Cummins Turbo Technologies has been working with Volkswagen to bring its new Constellation range of trucks to the Brazilian market. Initially consisting of three chassis models; designated 17.250, 19.320 and 24.250, the range is designed to enlarge Volkswagen's share in the challenging Brazilian market, which is one of the biggest in the world, worth around R$ 8 billion (approximately US$ 3.5 billion), with some 80,000 units sold annually.

Development of the Constellation range took four years, involving 200 engineers and technicians, with around 7 million kilometres of track and highway testing throughout South America as well as in Africa and Europe. Key driveline features include the Holset HX40W turbocharged Cummins diesel engines, acknowledged for their robustness and reliability.

The range also boasts an all-new and distinctive cab. The engine specified in the 17.250 and 24.250 chassis is Cummins 5.9 litre Interact model, based on the company's well-proven ISB diesel. Meanwhile the heavier-duty Constellation 19.320 is powered by the 320hp-rated 8.3 litre ISC engine, newly developed for the Brazilian Volkswagen application.

South American truck operating and climate conditions are uniquely demanding, which meant Cummins Turbo Technologies had to address particular thermal issues. Some redesigning and rematching of the turbocharger was therefore required. After an initial case study, it was decided to redesign the turbine housing, through new computer modelling, fatigue simulation and pattern making. Prototype examples were then created for extensive gas stand testing, where the robustness and capability of the revised installation was verified. The engineering team based in Brazil, received vital support from their mid-range application engineering colleagues at Cummins Turbo Technologies' headquarters in Huddersfield, UK.



Using Volkswagen's profound local knowledge of the South American commercial vehicle market and the local operating and servicing needs of Brazilian fleet engineers, in combination with the company's advanced technology experience in Europe, a robust and beautiful new truck has been created.

Cummins Turbo Technologies looks forward to working with its new OE customers in India and Brazil. We are committed to providing the best in class product performance, quality and service, working in partnership with our customers to ensure standards of engine performance and long-term reliability that add up to satisfaction for the end-user.

Images supplied courtesy of Volkswagon

Global Support

Written by Alison Smith, Marketing Co-ordinator

Turbocharging is becoming indispensable as engines are required by environmental legislation to meet ever tougher emission standards. Cummins Turbo Technologies, as a technology leader in the now intensely specialised field of turbocharger development, continues to invest in its new and existing production and support facilities.

Last year was another busy year as Cummins Turbo Technologies expanded its worldwide operations in Asia, Europe and North America. A new plant in Charleston, South Carolina, USA was announced in April 2005. The US$ 13 million investment in the new 110,000 sq ft (10,000m^2) purpose built facility will create over 180 new jobs and increase capacity by 200,000 units per annum, while allowing further room for expansion. The stand alone plant will focus on heavy-duty turbocharger manufacturing, serving North American and other global markets.

Increase capacity by 200,000 units per annum, while allowing further room for expansion

In September, a ground-breaking ceremony took place at Charleston to mark the start of construction of the new facility in the Palmetto Commerce Park. The offices are to be opened in May 2006, with production scheduled to commence in July.

In October, Cummins Turbo Technologies opened its new office in Pune, India. It will complement the existing Indian joint venture operations in Dewas and Pune, providing support, not only to the operations in India, but to all facilities around the world. The support will cover marketing, financial analysis, material flow and logistics, warranty and reliability analysis operations as well as new product introductions.

Paul Ibbotson, Managing Director, Cummins Turbo Technologies commented, "We are totally committed to dedicated and genuine partnerships with both customers and suppliers. We have a number of OE customers in India and expect this market to grow. This new office will not only support our India operations, but enable us to provide a high level of product support to all our customers worldwide".

The Aftermarket Division in Amersfoort, The Netherlands

Opening of the new Pune office in India

Finally, to improve our aftersales support, Cummins Turbo Technologies, Aftermarket Division in The Netherlands, has moved into a new larger facility in Amersfoort in order to cope with the growing demand.

Martyn Howorth, General Manager, Worldwide Aftermarket, commented, "The European aftermarket division has grown hugely in recent years, making the strong team that today supports distributors in Germany, Scandinavia and Eastern Europe".

Ground breaking ceremony in Charleston, USA

The Use of Application Guidelines

Written by Pierre French, Chief Engineer - Customer Engineering

Holset turbochargers are designed to functional standards that match reliability and performance demands over the widest range of applications. Cummins Turbo Technologies designers and development engineers endeavour to gain as full an understanding as possible of the intended missions of the engines for which the turbocharger is destined. It follows that they strive to ensure that the core design principles applied to each turbocharger family satisfy the widest possible range of markets and applications. This can often bring challenges.

Problems can arise in the field either before or after volume production of the engine gets under way, especially if good practice is not followed by all parties involved. Such problems tend to fall into four categories:

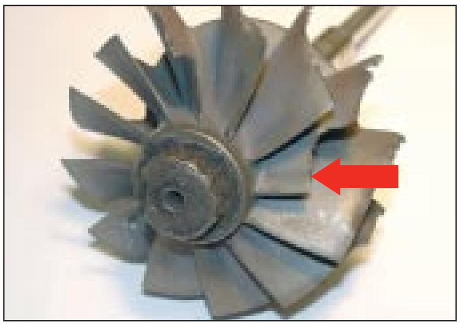


Fig 1 - Fracture of a turbine wheel

1. Fracture of compressor or turbine wheels through high or low-cycle fatigue (Figure 1).
2. Cracking of end housings due to thermal or mechanical loading (Figure 2).
3. Failures of bearings or seals resulting from a wide range of possible factors, typically associated with oil supply and drainage.
4. Problems with joints, attached parts or the turbocharger housings, due to excessive vibration or structural loading. Our experience indicates that attachment of boost pipe parts is particularly difficult to get right.

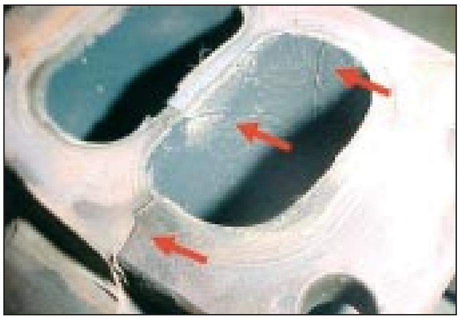


Fig 2 - Cracking of a turbine housing

Range of Applications

Turbocharged diesel engines can be found today in a huge variety of applications, both on and off highway, powering cars, trucks, buses, marine craft, earthmovers, agricultural machinery, generator sets, compressors and many other pieces of powered equipment. The way in which the engine is required to deliver its power and torque through its load and speed range can potentially have a dramatic effect on the performance, life and reliability of the turbocharger.

Turbocharger Use Success Factors

Engine turbocharger systems are being stretched to meet ever more sophisticated applications, which mean that turbocharger components are being worked closer to design limits. It is important to recognise potentially more arduous operating conditions from the outset by seeking out differences and similarities to existing known specifications so that realistic assessments of durability and reliability can be made.

To obtain an efficient, reliable and durable turbocharger several key areas need to be considered.

1. The turbocharger must be aerodynamically well matched to deliver the air requirements of the engine under steady state and transient conditions. The conditions due to altitude must also be considered.

Cummins Turbo Technologies has adopted a proactive approach to product application engineering

2. The turbocharger must be applied within the design limits of the components used in the turbocharger; such as turbocharger speed, temperatures of compressor outlet and turbine inlet and structural loads added by mating parts and engine vibration.

3. The turbocharger must function effectively in the engine and vehicle environment. It must physically fit within the allocated space with appropriate clearances and must allow appropriate service access. It must not present additional safety hazards to the vehicle and should not cause or suffer from high under hood ambient temperature, which could cause failure to engine or vehicle components.

4. The turbocharger should be effectively supplied with oil and air;
Oil - correct pressure, clean, no delay on start, temperature neither too hot or cold.
Air – clean, neither too hot or too cold, low pressure drop before the compressor.

Use in Real Applications

The use of a turbocharger in real applications should also be considered, since other factors can have an influence on life and effectiveness of the unit.

- Speed time history of the turbocharger rotor to avoid fatigue of rotating components.
- Exhaust time/temperature history to avoid turbine housing cracking.
- Use of exhaust brakes or other connected devices for seal life and crankcase blowby control.
- Service history of the engine - avoidance of carboning and wear of bearings.

The list is not exhaustive, but shows areas where problems can arise if best practice is not followed.

Turbocharger Application Guidelines

Cummins Turbo Technologies has adopted a proactive approach to product application engineering, making available to its OE customers best practice advice and carefully defined data on limitations of use.

To ensure a consistency of approach, the Turbocharger Application Guidelines database has been developed over the last six years, bringing these best practice and use limitation objectives together on a PC.

The Turbocharger Application Guidelines are designed to clearly illustrate turbocharger application best practice, though they are not intended to replace Cummins Turbo Technologies' formal engineering approval processes. It can best be regarded in the spirit of prevention rather than cure as a tool aimed at avoiding problems rather than fixing them. The guidelines nevertheless include advice should post-installation problems arise.

The Turbocharger Application Guidelines are broken down into several areas of expertise:

Turbocharger Sub-systems – Nine areas are covered with descriptions of function and best practice for each;

- Induction and compression
- Turbine and exhaust
- Bearing system, including seals
- Compressors and turbines
- Matching for duty cycles
- Control systems
- Connected sub-systems
- Installation design
- Life cycle considerations

Application Limits - Three areas are covered stating quantitative 'not to exceed' criteria for a wide variety of applications;

- Turbocharger speed limitations for different duty cycles
- Temperature limitations for different applications
- Structural limitations of use.

The continuous monitoring, development and improvement of these limitations are the subject of major efforts at Cummins Turbo Technologies, and will be described more fully in future editions of HTi.

Fig 3 - Movie showing MWE™

Calculation Methods - Common and consistent methods for predicting turbocharger operating parameters;

- Engine matching simulation
- Altitude prediction

Useful Tools

- Turbocharger orientation calculator - shows clearly mounting angle and position
- Variety of movies showing functions of key parts (Figure 3)

Turbocharger Features - Shows how Cummins Turbo Technologies formally assesses its applications;

- Turbocharger Application Failure Mode and Effects Analysis (FMEA)
- Turbocharger installation checklist

'The Turbocharger Application Guidelines' is a database which runs securely on a PC. It can be updated via the internet and revised files can be downloaded by Cummins Turbo Technologies engineers and OE customer engineers.
In the field if necessary, the database can also be accessed via a CD. Different levels of access to the Turbocharger Application Guidelines are available, depending on customer need and confidentiality considerations. Updating is quick and simple, whether just a minor change or the addition of major new content is involved. Typically there are major revisions every six months.

How do you make a Shaft & Wheel?

Written by David Wescott, Technical Specialist - Manufacturing

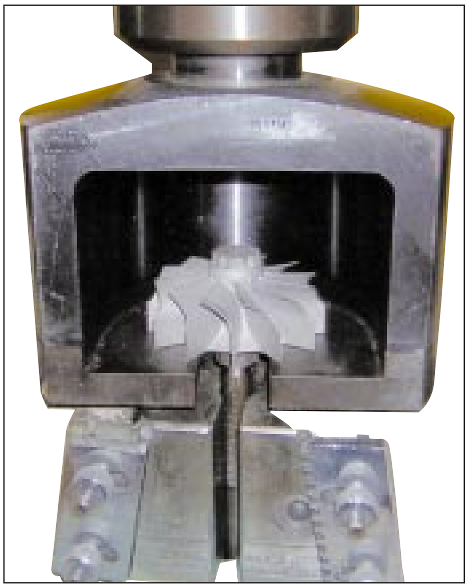
At the heart of every turbocharger is its shaft and wheel assembly, which along with the impeller forms the turbocharger rotor. Its function is to convert the exhaust gas flow into rotary motion of the turbine wheel and transmit this through the bearing supported shaft to drive the compressor's impeller.

The turbine wheel, rotating with the compressor impeller at up to 150,000rpm, is exposed to engine exhaust gases typically around 700ºC. Under such challenging thermal and physical conditions the shaft must retain the impeller in perfect alignment with the bearings.

Producing a shaft and wheel to meet such specific demands is a technique that has been developed and refined by our manufacturing engineers over many years. Cummins Turbo Technologies now produces approximately two million shaft and wheels assemblies annually, at its plants in China, India, UK and the USA. The shaft and wheel is a core component, necessarily manufactured in-house, where years of experience have gone into the critical production processes needed to ensure our quality based reputation.

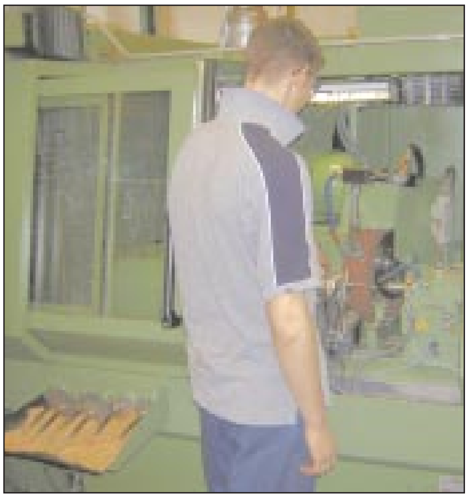
How is a shaft and wheel manufactured?

Perhaps the most vital component at the beginning of the manufacturing process is the Inconel austenitic nickel-chromium-iron alloy turbine wheel, a high strength investment casting. Inconel is a material that manufacturing engineers dislike. It is designed to withstand high temperatures, with an inevitable trade-off in machineability. Therefore a casting process has been developed and progressively refined to provide a casting profile that requires minimal machining. In practice, the only turbine wheel machining undertaken in-house by Cummins Turbo Technologies is to 'mass centre' the hole in the nose of the wheel. As the name implies the hole is positioned at the centre of mass of the casting, not at its geometric centre, in order to ensure perfect balance in the finished component. The centre hole is used to locate the turbine wheel throughout the manufacturing processes.

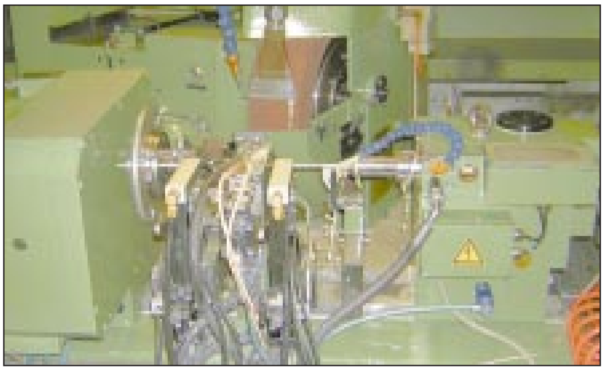


Tensile testing the friction weld joint.

Starting life as a steel forging, the shaft is friction welded to the turbine wheel. Friction welding was developed in the 1980s as a relatively low cost and reliable welding process, which proved ideal for attaching a turbocharger's comparatively soft steel shaft to the much harder turbine wheel investment casting. More traditional welding techniques had proved less than satisfactory, but intensive development of friction welding led to a process that is consistent and reliable.



Loading a shaft and wheel into the diameter grinder.



Finish grinding the shaft & wheel - showing steady rest and in process gauges used to maintain shaft diameter tolerances.

During the process, friction between a rotating and a stationary component causes the two metals to become red hot, at which stage pressure is applied to forge the parts together. Typically the shaft length is reduced by 3mm during the process. Quality is controlled by careful monitoring of the process parameters, notably speed and pressure. To ensure effective process control, random samples of the conjoined turbine/shaft component are regularly tensile tested to destruction. Surprisingly, a typical friction welded joint with a surface area of only 2cm sq will take a tensile load of over 10 tonnes before fracture. Furthermore, the joint is usually stronger than the parent metal.

Gauging a finish ground shaft and wheel.

Welding is followed by turning the shaft diameters in a lathe prior to precision grinding to finished tolerances. Before grinding, the bearing diameter of the shaft is induction hardened to provide the required durable surface match for the journal bearings. Induction hardening produces a hard surface on the shaft up to 2mm deep, while retaining a softer inner core in the shaft to maintain strength against potential shock load fracture.

Final grinding of shaft diameters is done on CNC (computer numerical control) grinding machines able to work to the required size, straightness and roundness tolerances on all shaft diameters. Quality is assured through the use of multiple function electronic gauges able to measure all the vital dimensions simultaneously. Statistical process control and calculation of the ongoing capability of the process is provided at the same time.

After the shaft diameters have been finish ground, the turbine wheel profile must be machined; another specialised Inconel machining operation. The hardness of the material means that the profile must be ground. Tolerances on size and concentricity must be maintained during the process to ensure an accurate match between the turbine wheel and its housing, thereby guaranteeing consistently high turbine efficiency.

Grinding and deburring the turbine wheel profile.

Seal ring grooves in the hub of the shaft may be turned or ground. Once again tight tolerances are essential on dimensions and surface quality as they influence oil leakage control in the finished turbocharger. Threads are then rolled on to the impeller end of the shaft. A strong concentric thread is required to retain the impeller, especially so in the face of customer demand for increased turbocharger performance necessitating larger impellers with small compressor clearances.

Almost every dimension on the shaft and wheel is critical to turbocharger performance

The final manufacturing operation is to balance the turbine wheel so that the shaft and wheel assembly is capable of running at operating speeds without vibration or excessive shaft movement in the bearing system. The shaft is dynamically balanced in two planes; at the nose and back face of the turbine wheel. This is undertaken on semi or fully automatic machines that measure balance of the turbine wheel, simultaneously calculating the precise amount of material required to be ground from each plane of the turbine wheel to bring it into balance.

Almost every dimension on the shaft and wheel is critical to turbocharger performance and durability. The manufacturing tolerances being achieved today are close to the best achievable in any volume manufacturing process.

Manufacturing processes developed by Cummins Turbo Technologies are applied globally to provide durable high quality components at the most economic cost.

The Effects of Altitude

Written by Owen Ryder, Senior Engineer – Air Handling

Anyone who has climbed mountains or has otherwise experienced high altitude will appreciate that the air is ‘thinner’ than at lower levels. There is less oxygen to breathe and devices that are of finite volume, such as lungs or for that matter diesel engines, will breathe less mass of air per breath.

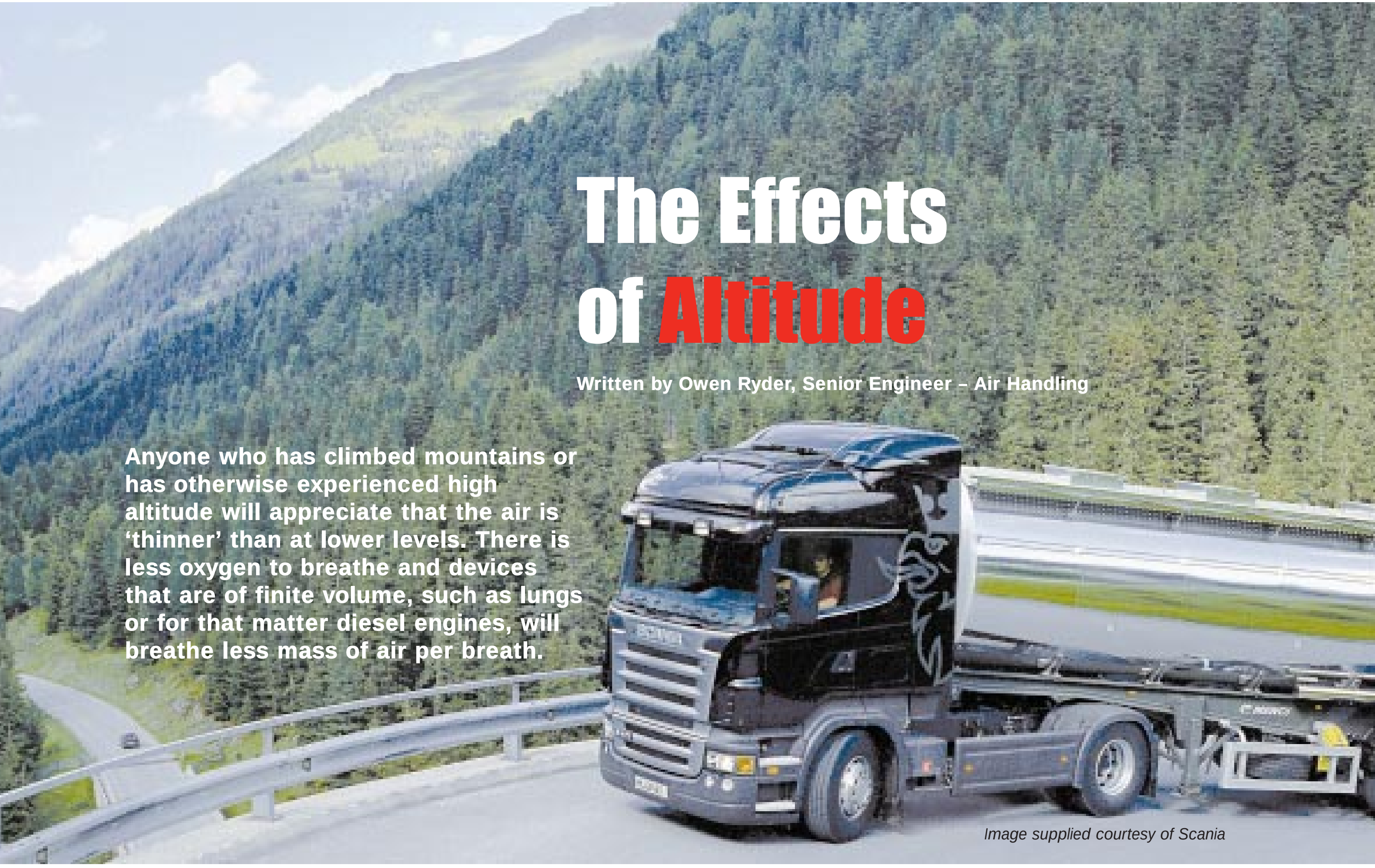


Image supplied courtesy of Scania

With a naturally-aspirated engine, the lower air mass flow at altitude reduces the air-to-fuel ratio, resulting in incomplete combustion, loss of power and a smoky exhaust.

In a turbocharged engine, the effect is less marked. The turbocharger will partially compensate for the lower density air because the turbine is ‘seeing’ a lower outlet pressure. This means that more expansion occurs across the turbine, spinning the turbocharger faster, which in turn increases the volume of air taken in by the compressor.

A turbocharger does not entirely compensate for the reduced air density. The truck driver negotiating an alpine pass will almost certainly be unaware that the turbocharger on their vehicle’s diesel engine is operating any differently at altitude, but a turbocharger designer or applications engineer needs to be aware of the effects.

Let us consider an example. At sea level, the ambient pressure is, by definition, around one atmosphere, or 1 bar. The turbocharger adds an extra 1 bar gauge pressure so the engine receives 2 bar absolute pressure. This means the turbocharger compressor is operating at a pressure ratio (PR) of 2:1.

Compare this with an extreme situation at 5,000m altitude. Here, the atmospheric pressure is only around 0.5 bar. The turbocharger adds an extra 1 bar gauge pressure, so now the engine receives 1.5 bar absolute pressure. This means the compressor is working at a higher pressure ratio of 3:1 (see Figure 1).

As the engine’s absolute pressure has dropped from 2 bar to 1.5 bar, the air density in the engine will have dropped. The result is that the engine air mass flow reduces, even though the compressor is rotating faster in order to generate the higher pressure ratio.

Clearly, as altitude increases and air density diminishes, the operating conditions of the turbocharger cannot adapt to the changes indefinitely. Eventually the engine would be starved of sufficient air to burn the fuel and the turbocharger would overspeed. Turbocharger speed could rise as much as 16% when climbing from sea level to an altitude of 2,000m. Therefore, engines have to be equipped with power limiters that reduce the engine fuelling once the atmospheric pressure has fallen below a pre-determined value.

The altitude induced speed increase must be calculated for each new turbocharger application and speed limits set accordingly. This calculation is done by Cummins Turbo Technologies application engineers, with determination of the engine’s altitude performance forming an integral part of the application approval process. This ensures that regardless of the engine’s operational altitude at any given moment, the turbocharger will always get the best available performance from the engine.

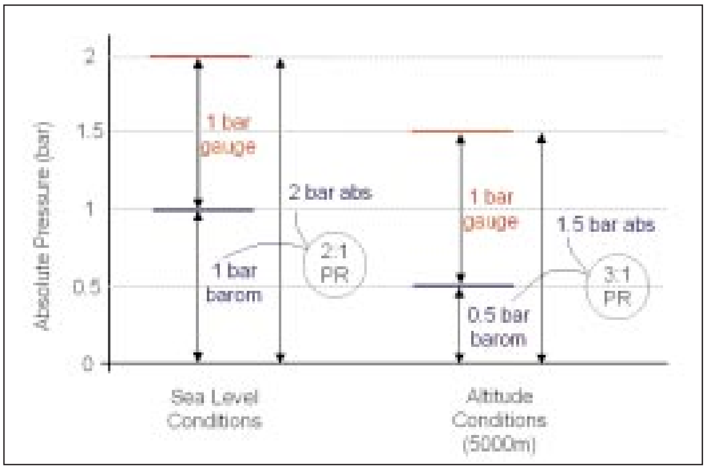


Fig 1 - Absolute pressure at sea level and altitude.

Altitude (m)	Pressure (mbar)	Temp (°C)	Density (kg/m)
0	1013	15	1.225
500	955	12	1.167
1000	899	9	1.111
1500	846	5	1.058
2000	795	2	1.007
2500	747	-1	0.957
3000	701	-5	0.909
3500	658	-8	0.863
4000	616	-11	0.819
4500	577	-14	0.777
5000	540	-18	0.736

Fig 2 - Air properties at altitude.

Changes in the Indian Market

Images supplied courtesy of Tata Motors Ltd.

Written by Akshay Jain, Marketing Co-ordinator & Sara Walls, Communications Co-ordinator

India's automotive industry has shown strong growth over recent years, stimulated by a combination of factors: Economic liberalisation, strong economic growth, improved transport infrastructure and the availability of more modern cars and trucks have all contributed to the increase in vehicle manufacturing in India. Further stimulation of car and truck sales has resulted from low interest finance and price discounts introduced by dealers and manufacturers.

During the period from January to September 2005, the market saw an increase in automotive manufacturing and assembly of over 16%. The fastest growth in volume terms has come from the commercial vehicle sector. Between 1998 and 2004, output of trucks, buses and vans rose by a spectacular 280%. Passenger car output over the same period went up by a slightly more modest 220%.

Until the mid 1990s, India's automotive industry in output per capita, lagged far behind that of many other countries. It has since made up lost ground, as India has become what amounts to an outsourcing hub for vehicle manufacturers worldwide. Rising sales and strong growth prospects heightened the value of automotive industry stocks in July 2004, when foreign institutional investors increased their stakes in key automobile companies like Ashok Leyland, Hero Honda, Mahindra & Mahindra, Maruti Udyog and TVS Motors. Previously the Indian automotive sector comprised a limited number of indigenous companies. However, after the sector was opened up to foreign direct investment in 1996, numerous global car giants started to move in. By 2002, Ford, GM, Honda, Hyundai, Mitsubishi and Toyota had set up Indian manufacturing bases.

India is a country the global automotive industry cannot ignore

Another boost has come from stringent government imposed exhaust emission regulations, aimed at establishing standards comparable with those enforced in Europe, North America and Japan. That in turn created demand for technology infusion backed by corresponding investment. The need to reduce pollution has led to emission control through Indian government regulations, achievable through environment friendly technologies. The Indian equivalent of Euro 3 standard is currently being introduced whereby for diesel powered vehicles, turbocharging plays an essential role in emission control.

A growing domestic market is driving current growth as Indian automotive manufacturers gear up to meet Euro 3 and subsequently Euro 4 emission standards. Multinationals are expanding capacities or establishing new plants on greenfield sites to meet the burgeoning demand. However, as industry analysts have pointed out, the additional production capacities will be used also to supply global markets, because India is seen as an economically attractive manufacturing and engineering base. According to industry estimates, while the cost of an average automotive design programme in Western Europe can be as high as US$800 per hour and even higher in the USA, equivalent costs may be as low as US$60 per hour in India, with no compromises in work quality. Indian based automotive companies are already moving aggressively into foreign markets.

For example, Indian tractor and utility vehicle maker Mahindra & Mahindra has emerged as the fourth largest agricultural tractor brand in the USA in the 15 to 90hp segment.

The company has also established thriving markets in Latin America and South Africa. Tata Motors Ltd, one of India's leading truck producers, acquired a Daewoo truck manufacturing unit in South Korea in 2004. Tata Motors plans to introduce a new range of heavy-duty trucks in India in the next 12 months. These new models, with engines in the 200 to 400hp category, built for operating weights up to 49 tonnes, will be launched initially in India and other selected countries as part of Tata Motors' longer-term global market strategy.

Cummins Turbo Technologies opened its production facility in India in 1995 through its joint venture company Tata Holset, based at Dewas in Madhya Pradesh. The new plant will enable Tata Holset to double capacity to 400,000 units per annum in the next two years. It comes as a further move in Cummins Turbo Technologies' strategy of expanding its worldwide manufacturing capacity, which last year saw the opening of a new world class facility at Wuxi in China to support the growing numbers of engine manufacturers setting up plants in China.

The new facility at Dewas is an expansion of the established Tata Holset facility and will enable the joint venture company to maintain the same global high standards in the manufacture of turbochargers and in the provision of customer service for which other Cummins Turbo Technologies facilities around the world are already recognised.

Indeed, India is well on its way to become an outsourcing hub for global automotive manufacturers; already Audi, DaimlerChrysler, Ford, GM, Isuzu and Nissan have set up outsourcing offices in the country, with an estimated combined budget of approximately US$1.5 billion. Leading component makers, like Caterpillar, Delphi and Visteon, have also chosen India for their future manufacturing expansion plans.

Nevertheless, according to Jagdish Khattar, Managing Director of Maruti Udyog Ltd, India's largest car maker and a Suzuki joint venture partner, "India still has a long way to go to become a global force", he says, pointing out that China is already recording four times India's 900,000 annual car sales. Analysts say that if Indian companies hope to secure a significantly bigger slice of the global market they need to increase their global presence considerably.

However, Joginder Singh of Ford feels that India's automotive industry will increasingly make its presence felt, primarily because it is a country the industry cannot ignore. "Two-thirds of a car is built from outside suppliers. That's a big cost item and companies can cut costs to a large extent in places like India and China", he says, adding that "we cannot ignore either China or India, both of which are projected to be so huge that it would be dangerous to look only at one of them. They are showing the highest economic and industrial growth in the world. Any automotive maker would be foolish to ignore either of them".

Source: "The Economic Times" Dated October 27, 2005 and following websites: http://www.ibef.org, http://www.economywatch.com

Telemetry Testing

Written by Steve Jackson, Group Leader - Telemetry Section

All fluid machinery blades, due to the nature of their operation, are susceptible to blade failure. A turbocharger is no exception. Failure is induced when the blade is forced to deform from its natural shape as it is subjected to rotational and aerodynamic forces.

The modified compressor wheel houses the precision nut and radio transmitter for non-contact, data transfer.

Every blade has a series of set deformation shapes or mode shapes, at which it flexes. The shapes of these modes and the frequencies at which they occur, are determined by the physical properties of the blade, more notably its geometry and material.

When the rotor speed coincides with these modal frequencies, the blade vibrates, resulting in areas of alternating strain occurring between areas of out-of-phase deflection in accordance with that particular mode shape. If the strain is high enough or endured for a significant period of time, fatigue fracture will be induced. This usually results in the blade becoming detached causing catastrophic failure of the turbocharger. The solution to this problem is either avoidance or tolerance.

Avoidance may at first seem the obvious answer. It could be inferred that if the first mode frequency occurs at 4,000 Hz, for example, then the rotor will need to spin at 240,000 rpm. This is beyond the maximum operating speed of our turbochargers and hence, will not pose a problem. Similarly, second, third, fourth and higher vibration modes occur at higher frequencies still and therefore they are of no concern. There is however, a problem. Mode shapes are not just excited at this one 'fundamental' frequency but they are also excited at multiples and divisions of that frequency. The resultant deformation will be the same; it is just that the excitation period is, for example, doubled or halved.

The instrumented rotor assembly with a strain gauged turbine and a transmitter mounted compressor.

An analogy is pushing a child on a swing. If the child's parent pushes the swing each time the swing is nearest them, the swing will continue to swing indefinitely. In this case, the frequency of the push is equal to the frequency of the swing's oscillation and could be likened to the 'fundamental'. The same effect could also be achieved by pushing the swing every second oscillation, ie halving the excitation frequency. Also, if both parents push the swing from opposite ends of each stroke, the same result is achieved from doubling the excitation frequency, ie pushing twice per oscillation. However, the swing will not achieve this swinging motion if the parents do not push at the right time. If the push is made out of phase with the swing's natural frequency of oscillation, the swinging motion is not achieved despite excitation energy being supplied in the form of the parent's pushes.

The division of this fundamental is termed an order. Hence dividing 240,000 rpm by 2 gives a second order speed of 120,000 rpm, placing it in the operating speed range of the turbocharger's rotor. Dividing the original figure by 3, 4, 5 and so on (for third, fourth and fifth orders) brings to light more operating speeds where Mode 1 vibration will occur (80,000 rpm, 60,000 rpm, 48,000 rpm and so on respectively). The situation becomes even more complicated when the next mode, Mode 2, is taken into consideration. If, for example, this occurred at 6,500 Hz, then deformation at this shape would be observed at 390,000 rpm, 195,000 rpm, 130,000 rpm, 97,500 rpm, 78,000 rpm, 65,000 rpm, etc. Add the interactions of Mode 3, Mode 4, Mode 5, etc. and the operating range is filled with failure inducing interaction frequencies.

Therefore, with avoidance out of the question, Cummins Turbo Technologies deals with this phenomenon by means of tolerance. This is achieved by design optimisation, balancing the conflicting parameters of efficiency against component failure.

Turbine Wheels with strain gauge attached.

Mode 1 results.

The physical measurement of strain within a blade design is performed by Cummins Turbo Technologies' Telemetry Section in both China and the UK. We are the only company in the field of turbocharging that uses physical strain measurement in its approval process. All aspects of the system, which may have an effect over the resulting strain, are taken into account. These include new wheel and housing designs and evolutions of existing designs for both turbine and compressor wheels.

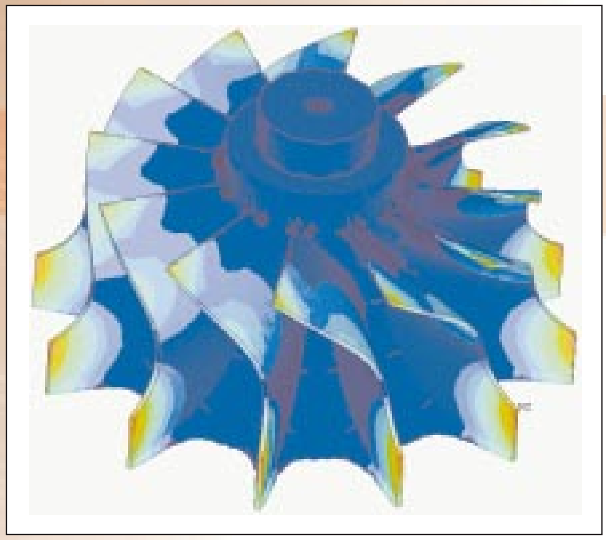
We are the only company in the field of turbocharging that uses physical strain measurement in its approval process

Strain is measured using specialist high temperature strain gauges mounted on the blades. Dynamic testing on both engines and test cells is by means of telemetric data transfer. In the first instance, test wheels are selected following a frequency survey of a representative batch of components. This is a semi-automated process, running on in-house software, which allows the frequency measurement of individual blade modes. The determination of the gauge's location is one of the most important aspects of wheel preparation.

This task is performed by the Applied Mechanics group who evaluate the strain regions of the blade using finite element analysis. Suitable positions are determined in order to generate the most accurate readings for one or more modes and to increase the life of the gauge which is subjected to high centrifugal forces during measurement.

Gauge positioning is carried out with the aid of a microscope. Each gauge is repeatedly ceramic cemented and oven-baked on to the blade to ensure that it will be able to tolerate the high temperatures and forces of the test. The lead wires of the gauges are fed axially through the previously modified shaft to connect with a short range radio transmitter mounted at the compressor end of the rotor. The compressor end, together with specially designed transmitter housing nut, is machined and modified to a very high tolerance in order to minimise any out-of-balance forces to which the components within the transmitter are subjected to during rotation. These modified components are then built into a standard turbocharger, which is fitted to an engine.

Engine speed and load is manipulated to achieve the necessary turbocharger rotor speeds for each blade-mode orders under investigation. The resulting strain is processed and Fourier transformed, in real time, using in-house designed and built hardware and software.

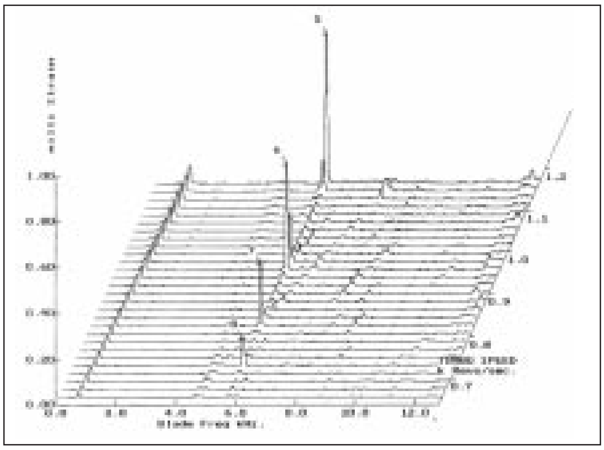


Mode 3 results.

The peak dynamic strain level for each rotational order is recorded and then displayed graphically as strain amplitude with respect to blade frequency and rotor speed. The system itself is versatile enough to measure different modal frequencies, allowing measurement of both fixed and variable geometry turbochargers. To establish continuity between projects, base tests are employed. These not only ensure that comparisons can be made between tests but also state that the individual tests are repeatable within themselves.

The results are then compared to values listed in a predetermined, strain assessment matrix that operates as an acceptance or rejection procedure for new designs. This matrix is based upon frequency survey data and is generated by the Applied Mechanics group. In addition to this approach, existing designs, which have been subjected to manufacturing changes, may also be compared to one another. Hardware is deemed acceptable in this case, if there is a favourable comparison for the changed item.

The Telemetry Section presents the physical evidence in the blade design's resilience to failure for new and existing wheel and housing designs. This has shown itself to be an invaluable, quality assurance tool in predicting a turbocharger's service life.



Waterfall Plot.