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.

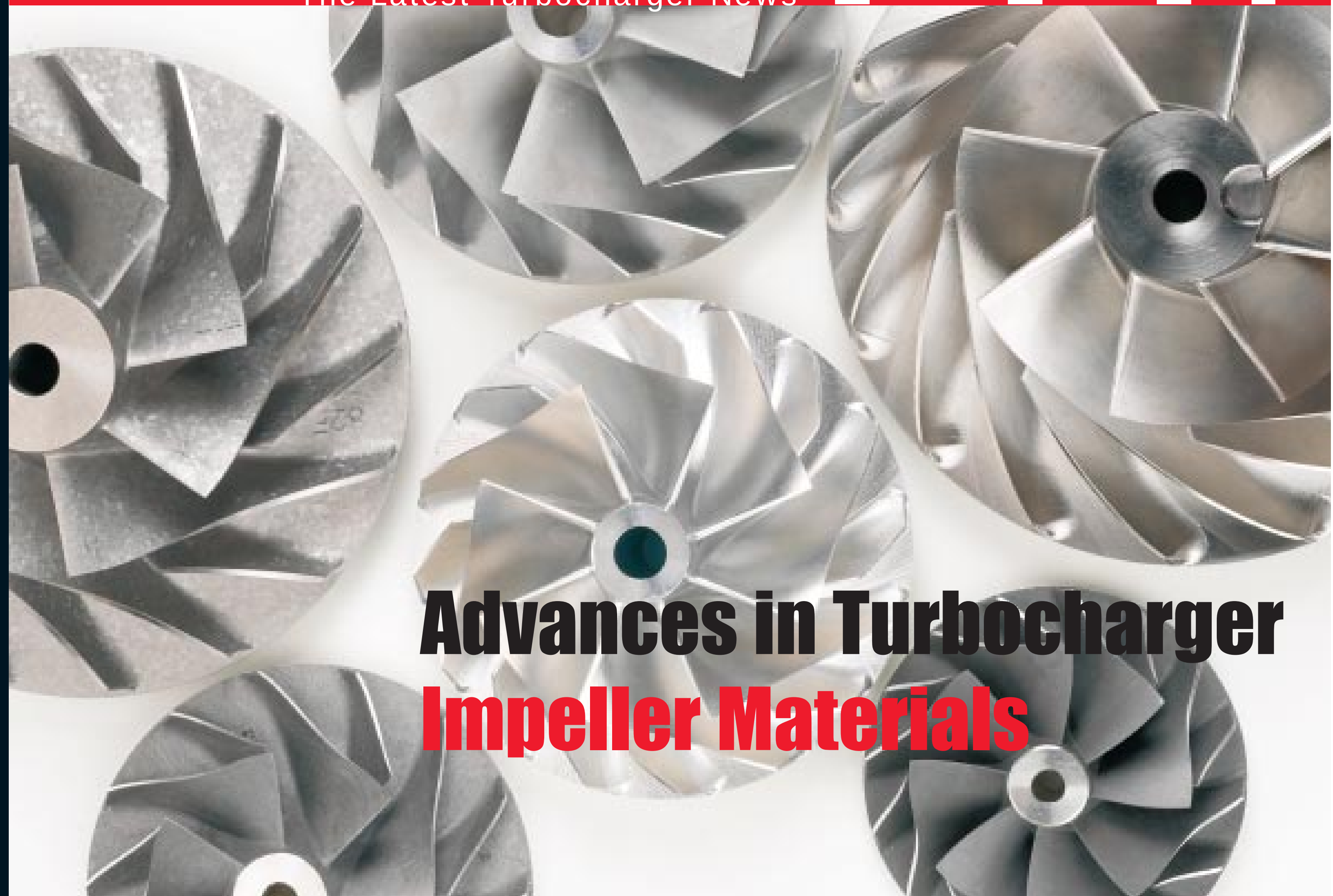
Our goal is to provide the lowest total cost solution for your turbocharging needs.

Part No. 3766118 Edition 7 Ref: AJS/OR

Turbo Technologies

HTi

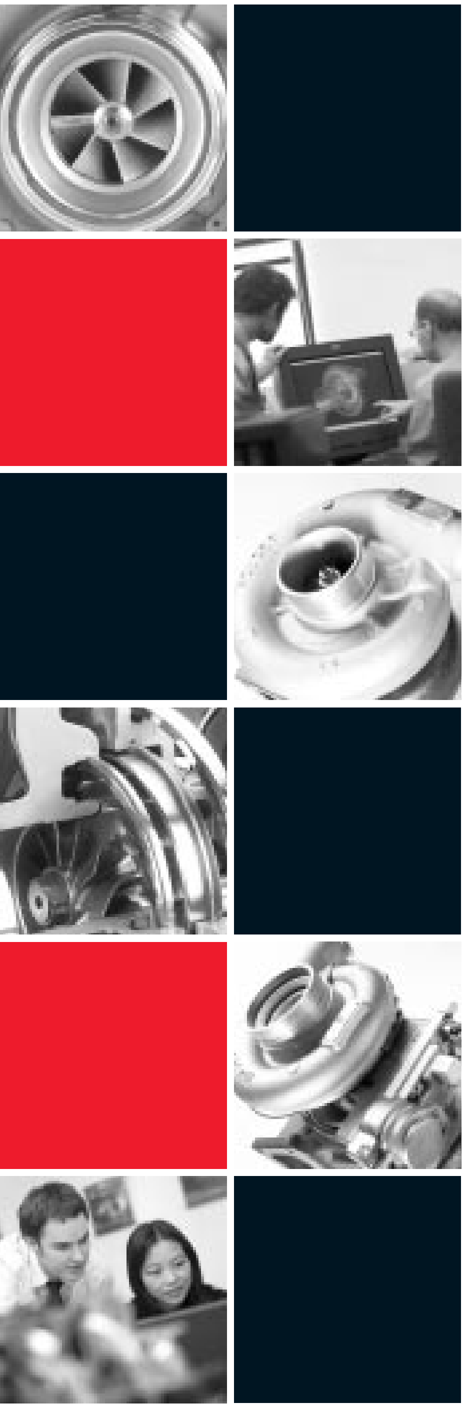
The Latest Turbocharger News



Advances in Turbocharger Impeller Materials

EDITION 7:

Turbo Technologies



Comments from the Leadership Team

In the past four years Cummins Turbo Technologies' sales and volumes have grown significantly, in-line with increases expected in a new company start-up. This is a phenomenal achievement, of which the company can feel justifiably proud. As greater numbers of on and off-highway diesel engines are subject to emissions legislation, this growth is projected to continue.

The strength of the technology embodied in our Holset brand and our proven ability to meet customer demands, in combination with optimised fuel economy and performance, has been crucial in strengthening our relationships with our customers and winning new business.

Winning new business is only desirable if that sales growth adds additional profit. To ensure that we leverage the required profit, we must understand and put in place the necessary global processes, systems and measures. Growing sales without commensurate infrastructure growth is fraught with risk.

One of my responsibilities is to look ahead in developing a business strategy for Cummins Turbo Technologies, which pulls together all of the functional elements that make for a successful organisation, ensuring that every department and indeed every individual is striving efficiently for the same goals and using aligned processes, in order to maximise our already well-proven strengths and deliver profitability targets.

Alison Snell

The growth that Cummins Turbo Technologies has achieved over many years is a testament to the strength of our organisation as it moves forward into a period of unprecedented growth. Everyone in the Cummins Turbo Technologies management team is facing the challenges and opportunities with immense enthusiasm.

Alison Snell
Business Development 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.

Turbocharger Potential in Brazil

Images supplied courtesy of Ford

Written by Rui Barbieri Filho, Engineering Supervisor & Ricardo Souza, Application Engineer

Brazil is a unique market for engines. Alternatives to regular fossil fuels have made more of an impact here than probably anywhere else in the world and engine technology innovations related to these fuels, mainly renewables, continue to appear. In the last three years, the gasoline automotive market has been 'invaded' by bi-fuel vehicles that can run happily on either bio-ethanol or gasoline or any blend of the two. As ethanol prices can be 40% cheaper than gasoline, more than half the passenger cars sold in Brazil today (1.8 million a year) are bi-fuel compatible, despite their fuel consumptions being on average 30% higher.

Automotive use of natural gas is also growing significantly and has reached 50,000 conversions per year. The relatively expensive upgrade of a gasoline engine to run on natural gas can be readily justified since fuel cost per kilometre is reduced by as much as 60%, therefore a car that covers more than 20,000km a year recoups the initial cost in only a year.

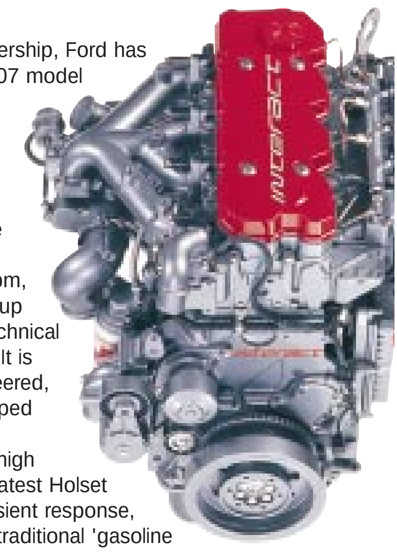
However, the growth in natural gas use has been weakened by the recent natural gas crisis in Bolivia, after the Bolivian government announced administrative restrictions against multinational refineries on their territory. This has caused alarm in Brazilian and other South American markets, since Bolivia is also the main natural gas producer, leading to natural gas price increases and supply uncertainty.

In addition to natural gas fuel developments, we have seen the start of production of biodiesel, with obvious implications for truck and bus engines. It will be introduced in 2008 initially with a 2% blend of the diesel fuel sold to on-highway customers at fuel stations. Since the Brazilian automotive diesel market amounts to over 32 billion litres a year, the 640 million litres of 'neat' biodiesel needed to make up a 2% blend will require 1% of the total plantable agricultural land area in Brazil amounting to 1.5 million hectares. With accompanying advances in diesel engine technology and production, biodiesel is beneficial for the environment without jeopardising other Brazilian agricultural activity. The plan is that the biodiesel content in marketed fuel will rise to an expected 5% blend 'strength' by 2013.

Automotive use of natural gas is also growing significantly and has reached 50,000 conversions per year.

In terms of vehicle numbers, the diesel market in Brazil has remained fairly constant in recent years, at around 500,000 units sold in 2005. However, a growing market within the diesel segment is for American style diesel pick-up trucks, used mainly in rural areas, where farm tracks and poor public roads have led customers to buy such vehicles, often with four-wheeled drive and high ground clearance. Last year, 80,000 diesel pick-up trucks were sold in Brazil. The heavy-duty pick-up truck market in Brazil is dominated by Ford's F250 model, of which around 8,000 examples are now sold annually amounting to 70% of the total in its weight category.

Looking to maintain its segment leadership, Ford has updated the F250 pick-up for the 2007 model year, improving its style, comfort and performance. The new variant is powered by a Cummins ISBe four-cylinder common-rail diesel, an engine familiar to commercial vehicle users in Europe, notably as the prime power unit in DAF Trucks' lighter LF chassis. Developing 200hp at 2900rpm, it has been tailored to the F250 pick-up application by Cummins' Brazilian Technical Centre, headquartered in Guarulhos. It is equipped with the new, locally engineered, Holset HE221W turbocharger developed specifically for this application. While contributing crucially to the engine's high power and torque performance, the latest Holset turbocharger also delivers a fast transient response, helping the diesel F250 to appeal to traditional 'gasoline only' drivers.

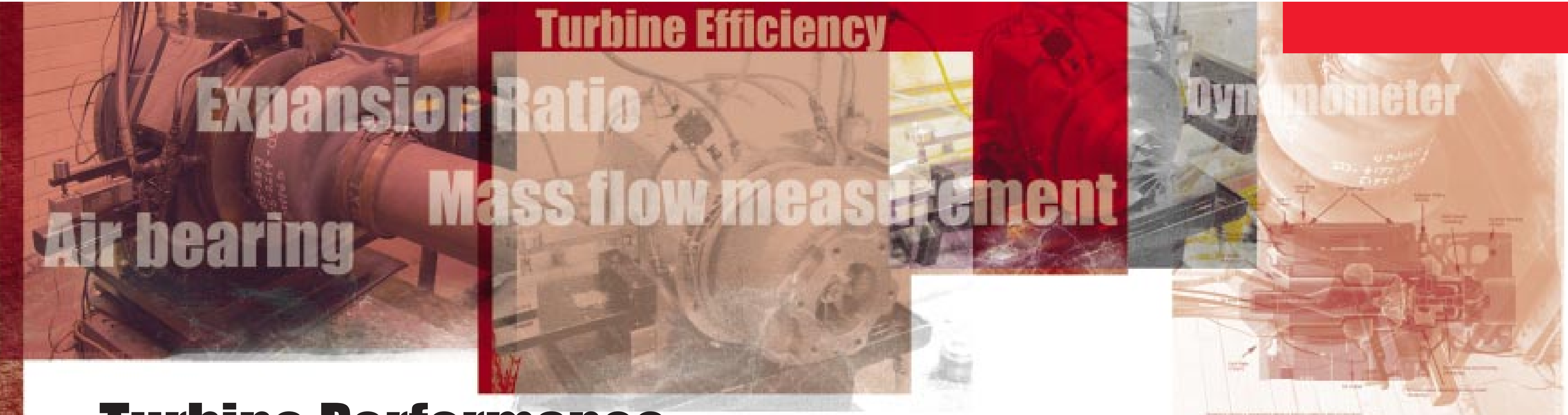


Cummins ISBe

New challenges were brought by the Ford pick-up application programme, not only for the Cummins Turbo Technologies team in Brazil but for their engineering colleagues in the company's technical centre at Huddersfield in the UK. Working together with Ford and Cummins, such key issues as noise, vibration, harshness and high altitude performance capability were met after extensive development programmes.

Subsequent testing included test cell approvals, transient and running noise tests, extensive road trials in Brazil and altitude tests in the Andes and other parts of South America.

Matching the advanced specification of the new ISBe engine, are numerous other features of the 2007 model year Ford F250 pick-up. They include reinforced suspension and a four-wheeled option, both designed to achieve the best possible ride and traction in the most difficult terrain. Buyers will be able to specify such cab comfort refinements as a DVD player, MP3 sound system and leather seats.



Turbine Performance Mapping

Written by John Hamilton,
Senior Mechanical Facilities Engineer

As Cummins Turbo Technologies' customers design new engines and emissions regulations are tightened, Holset turbochargers are required to meet increasingly demanding performance requirements.

To allow us to develop these new turbine stage components and support existing designs, we need to be able to measure the turbine stage performance.

The role of the turbocharger turbine stage on an engine is to recover energy from engine exhaust by turning it into rotational work. The work recovered is then transferred along the turbocharger shaft and used to drive the compressor stage. The compressor increases the air density in the engine inlet manifold increasing engine power output and efficiency. The characteristics of the turbine stage are also key to the emissions strategies used in modern diesel engines.

What is the Turbine Performance Test Data Used For?

Turbine stage performance test data is used to:

- Evaluate new designs of turbine stage components such as housings, wheels, variable geometry nozzle rings and wastegates.
- Validate the design methodologies used for new turbine parts.
- Provide data to allow engine matching.
- Compare the performance of components from different suppliers.
- Provide data for engine simulation software.
- Provide data for customer engine management systems.

What Turbine Data is Measured?

During testing, the turbine stage is run at a range of operating conditions and the primary characteristics of the turbine stage are measured as follows:

Turbine Efficiency – This is the percentage of work recovered by the turbine stage compared to the maximum amount of work that could be recovered by an ideal expansion of the inlet gas to the outlet pressure.

Turbine Flow Parameter – This is an expression for the flow of exhaust gas though the turbine stage at a given operating point. This is a function of the gas mass flow rate, the inlet temperature and the inlet pressure.

The turbine stage efficiency and flow parameter are measured at a number of operating points defined by:

Turbine Speed Parameter – This is a function of actual turbine shaft speed and the absolute temperature of the gas at the turbine inlet. This provides the x-axis for the map. A 'wider' map is one run over a wider speed range.

Expansion Ratio – This is the ratio of the absolute pressures at the turbine inlet and turbine outlet.

This data is then plotted as a 'Turbine Performance Map' (figure 1).

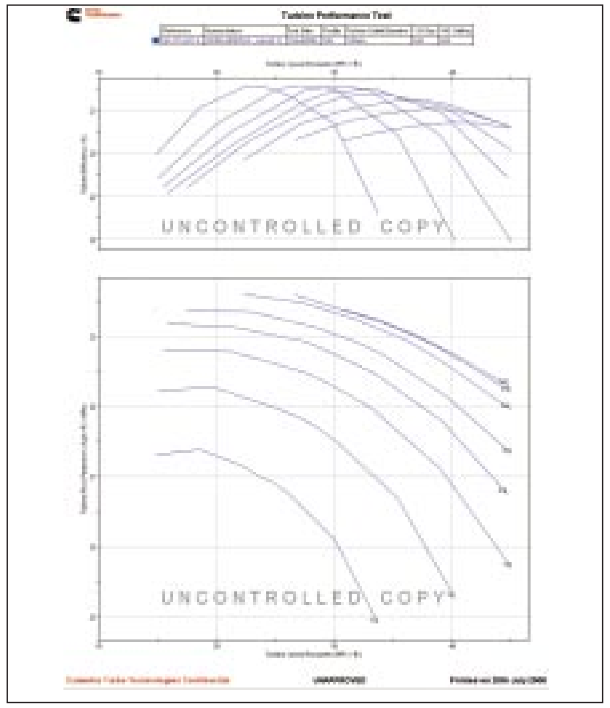


Fig 1 - Turbine performance map

When the performance of a turbine stage is being measured, the turbine is run at a range of shaft speeds while maintaining a constant expansion ratio. Each expansion ratio line comprises six equally spaced test points with two additional test points close to turbine peak efficiency. A performance map comprises a group of constant expansion ratio lines typically taken at 1.4, 1.8, 2.2, 2.6, 3.0 and 3.5 expansion ratios making 48 data points in all.

When testing a variable geometry turbine stage the nozzle ring is fixed in position during each map. A number of maps are then run with the nozzle ring in different positions. Typically a variable geometry turbine stage will have six or seven separate performance maps.

How is the Data Generated?

It is possible to measure turbine stage performance during engine testing or when testing a complete turbocharger on a gas stand test. However, at Cummins Turbo Technologies all our turbine performance maps are generated on a turbine dynamometer gas stand. For this type of testing, the turbine stage is built into the turbine dynamometer without the compressor and is driven by heated compressed air.

The main benefit of this test method is the width of the turbine map. One test generates sufficient data to cover all applications for a given turbine stage. Cummins Turbo Technologies is the only turbocharger manufacturer that generates all its turbine performance maps using this method.

Fig 2 - Mid-range dynamometer with turbine housing fitted.

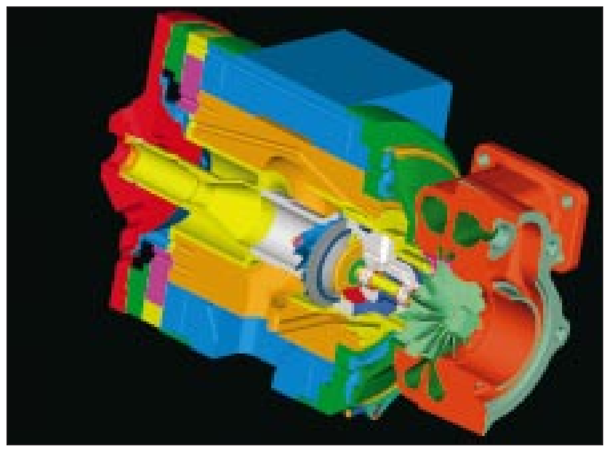


Fig 3 - Mid-range dynamometer section view

How Does a Turbine Dynamometer Work?

A dynamometer is defined as 'an instrument for measuring work' and is perhaps most familiar in the form of 'rolling road' installations used for measuring a vehicle's power at the wheels. During turbine performance testing, the turbine stage is built into the turbine dynamometer using a custom designed bearing housing. The turbine dynamometers at Cummins Turbo Technologies absorb the work generated by the turbine stage by using an oil brake. The 'load oil' in this oil brake acts on an impeller on the compressor end of the turbine shaft. By controlling the flow of load oil to the dynamometer it is possible to vary the braking torque and so control the turbine speed.

To measure work, the turbine dynamometers rely on Newton's third law of motion: "For every action there is an equal and opposite reaction."

The role of the turbocharger turbine stage on an engine is to recover energy from engine exhaust by turning it into rotational work.

As the load oil absorbs work from the turbine shaft it produces an equal and opposite reaction torque on the internal casing of the dynamometer. To allow this reaction torque to be measured, the internal casing of the dynamometer is mounted on frictionless air bearings. The air bearings used in the dynamometers are critical to the dynamometer performance. While there is no rotation at these bearings, the frictional losses must be close to zero even at high loads. The reaction torque is then measured using a load arm and load cell and the rotational work is calculated from the measured torque and the turbine shaft speed.

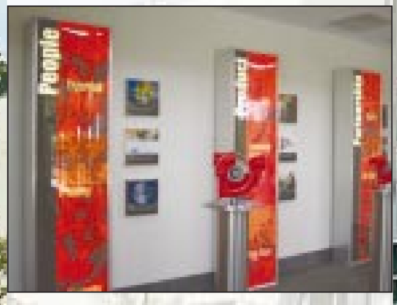
Turbine Dynamometer Facts and Figures

Cummins Turbo Technologies have been operating turbine dynamometers for over 30 years, during which time the dynamometer design has been progressively improved with six designs being used. There are currently two test cells in Huddersfield, UK, fitted with turbine dynamometers. The most recent of these dynamometers was installed in 2002 and is used for mapping high horsepower and variable geometry turbines. Some facts and figures for this dynamometer are below:

Maximum speed -	Up to 110,000 rpm
Torque range -	Up to 45 Nm
Peak power -	280kW (375hp)
Air bearing journal outside diameter -	254.000 / 254.002 mm
Air bearing journal inside diameter -	254.015 / 254.017 mm
Air bearing thrust load capacity -	10,000 N

Continuous Improvements

In the last three years significant improvements have been made to the two dynamometer cells. These improvements include work to improve dynamometer reliability, stability of the test point and upgrading of turbine stage adaptors. These improvements have led to significantly improved test productivity and repeatability. To help identify these improvements Six Sigma methods (Design For Six Sigma) are used to identify and implement these improvements to ensure our turbine maps provide first class information to the end user.



Second Charleston Plant Opens for Business

Written by Jodie Stephenson, Global Marketing Communications Leader

Cummins Turbo Technologies recently celebrated production start-up at its newest manufacturing facility in Charleston, South Carolina, USA. At 4pm on Friday June 30, the first heavy-duty Holset VGT™ turbocharger rolled off the new Cummins Turbo Technologies plant in Palmetto Commerce Park. It was a huge milestone.

Turbocharger shaft and wheels were produced at the plant, which is also responsible for final assembly. A new manufacturing execution system and materials resource planning system, namely Oracle 11i were used. All turbochargers manufactured subsequently passed the 'hot test' at our Leeds Avenue facilities. Full production in the Palmetto plant began on 17 July 2006.

On 21 July 2006, exactly ten months to the day of the initial ground breaking, the new plant was officially opened by Tim Solso, Cummins Inc. Chairman and Chief Executive Officer, joined by Paul Ibbotson, Managing Director, Cummins Turbo Technologies and North Charleston Mayor, Keith Summey.

Tim Solso commented, "The turbocharger business is an important part of the success of Cummins and we're pleased to be able to build on the good work being done at Cummins Turbo Technologies with this expansion. This state-of-the-art facility will allow us to further leverage the Holset product name and grow our business in markets around the world."

The new facility brings Cummins Turbo Technologies' number of worldwide manufacturing locations to six and builds on its existing presence in USA, Brazil, UK and its Asian joint ventures in China and India.

The Use of Limits in Applying Turbochargers to Engines

Written by Mike Dolton, OEM Applications Team Leader

In order to provide a reliable and robust product, Cummins Turbo Technologies provides guidelines for the use of its Holset turbochargers. The heavy-duty market contains a wide range of demanding applications and it is not practical to tailor a turbocharger to each individual use.

In many cases, the end use of an engine may not be known and so the exact conditions that the turbocharger sees in the field will vary. Problems arise when the turbocharger design criteria are exceeded in actual use and this can cause turbocharger failure, leaks, noise or poor performance.

Application Limits

To avoid the turbocharger running outside its design envelope, Cummins Turbo Technologies provides generalised limits, to be used in the absence of specific data for a particular use. These limits are used when there is no background data on an engine or when it is not possible to obtain or estimate real conditions in use.

The limits are particularly useful if the engine application undergoes a change in its purpose, for example, from a truck engine to a generator set or bus. The limits give targets for key matching parameters without having to take measurements in the field and their use will help to avoid turbocharger failures in service.

Fig 1 - Excessive engine temperatures

These turbocharger failures fall into five general categories:

1. Thermal cracking, creep or oxidation of parts
   - Cracked turbine housing.
   - Rubbing or distortion of turbine housings due to over heating (figure 1).
   - Compressor housing distortion due to over heating.
   - Compressor wheel failure due to creep.

2. Fatigue of rotating parts
   - Cracked compressor wheel (figure 2).
   - Cracked turbine wheel.
   - Turbine wheel blade loss.

3. Structural failure of the turbocharger or attached parts
   - Loose bolts.
   - Cracked flanges.

4. Failure due to out of specification engine conditions
   - High exhaust back pressure under engine braking.
   - High or variable exhaust back pressure due to aftertreatment.

5. Problems in the engine causing turbocharger failure
   - Dirty oil.
   - Broken engine parts going through the turbocharger.

The application limits deal primarily with the first four of these, however, guidance on avoiding problems with the latter item can be found in the Holset Application Guidelines CD as described in HTi Issue 6.

Application limits are categorised into four areas:

1. Speed
   - Turbine and compressor speed limitations defined by the type of application.

2. Temperature
   - Turbine inlet temperature limits based on use and material selection for the turbine casing.
   - Boost outlet temperature for compressor stage based on creep.

3. Structural
   - External load limitations.
   - Weight and torque reaction of external parts.
   - Applicable maximum vibration levels.
   - Built in stresses due to assembly.

4. General ‘not to exceed limits’
   - Exhaust braking back pressure.
   - Oil pressure.
   - Under hood ambient temperature.
   - Oil delay under start up.

The use of application limits will help to avoid turbocharger failures in service.

In each area, Cummins Turbo Technologies pools its analytical, product performance and test experience to arrive at generally applicable limits. This is done in a formal process involving Product Development, Application, Service and Technology Engineering areas, and the limits are controlled and published internally using QSI, the Cummins Turbo Technologies internal quality release process. Engineers can easily work from exactly the same set of limits wherever they are in the world.

Setting The Limits

The limits are decided using market sector average levels which meet Cummins Turbo Technologies target reliability numbers. These take into account altitude, geographic mobility and average annual usage of the equipment.

Geographic mobility is a major factor when considering setting limits, as high altitude will increase turbocharger speed and temperature.

Consider a truck operating in a large geographic area, for example, in China. Nearly all trucks move over wide areas that range from sea level to 5,000 metres.

However, it can be assumed that trucks operate at relatively low altitude for most of their life. The limits are set to achieve a fleet reliability based on the average truck.

Now consider an urban bus operating in South America; for example, Bogotá. City buses have a much smaller operational range, normally defined by metropolitan boundaries.
The average altitude of such routes is set by the city location. In the case of Bogotá, this is 2,600 metres, where the turbocharger speeds and temperatures are higher than those in cities at sea level.

Generators and many types of industrial equipment also have limited geographic mobility. Indeed, many are restricted to single sites, so in all of these cases, speed and temperature limits are specified independently from their altitude of operation.

How The Limits Are Derived

Speed limits are calculated using Cummins Turbo Technologies’ life prediction routines. These link duty cycle measurement, design stress limitation and material properties to the required life, geographic distribution and field performance. The speed limit value is selected to achieve Cummins Turbo Technologies reliability and durability goals.

Temperature limits are derived from a combination of field reliability data, market targets, Finite Element analysis and thermal duty cycle information.

Structural limits are in many ways the most complex limit to approach analytically. ‘Not to exceed’ limits are defined based on test cell vibration data, hot test mechanical assessments, modelling and reference to best practice from the field.

Often it is not possible to identify the exact load case for the turbocharger where connected parts are attached to a vehicle chassis. In these cases we seek to use best practice as described in the Holset Application Guidelines CD. Where loads are not known or difficult to estimate, best practice is sometimes the only route to designing a reliable installation.

Cummins Turbo Technologies’ Application Engineers use a checklist contained in the Guidelines as an effective method for evaluating installations.

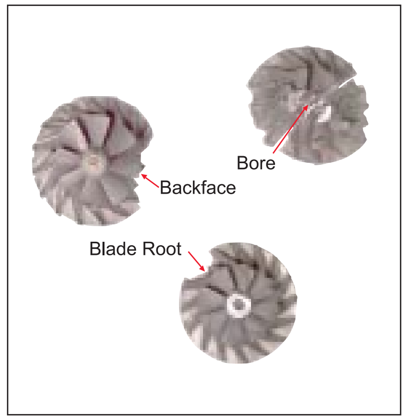


Fig 2 - Three typical impeller failure modes

Other Limits

Other limits exist for back pressure braking, ambient conditions under the hood and oil delay which supplement a turbocharger’s basic functional needs. These are all to be found in the Holset Application Guidelines CD, available to Cummins Turbo Technologies partners involved in developing and applying turbochargers in their own markets.

Looking Ahead

A ‘one size fits all’ approach is not appropriate when individual customers’ performance and durability targets have to be met. Many application and local geographical factors can have an influence on turbocharger operating conditions and Cummins Turbo Technologies is committed to evaluating these effects with our customers. Once the circumstances are understood, adjustments can be made. In the continuous improvement process, this becomes another piece of data that can be used to refine the limits that Cummins Turbo Technologies specify.

Diesel Engine Emissions Regulations and Solutions

Written by Owen Ryder, Senior Engineer – Air Handling

Air pollution and global warming are topics frequently covered in the news as we become increasingly concerned about the earth's atmosphere. The burning of fuel in vehicles has a significant impact on these environmental issues and governments around the world have legislation in place to reduce these harmful emissions.

Emissions Legislation

Emissions legislation is not a new idea; California started limiting emissions in 1959 and full USA legislation came into force in 1987 with Europe following in 1992. The requirements for the USA are also used in Canada and parts of South America while the European standards are used in China, India, Russia, South Africa and South America, although the time for implementation varies (see figure 1). Japan controls its own vehicle emissions separately.

The four main pollutants controlled are Nitrogen Oxides (NOx), Particulate Matter (PM), Hydrocarbons (HC) and Carbon Monoxide (CO), with NOx and PM being the two critical pollutants for heavy-duty diesel engines. The amounts of pollutants allowed are continually being revised so that engines are becoming cleaner and cleaner with each new engine introduction, requiring the development of new products every three or four years.

Not only do the allowed levels of pollutants change, but the test methods for assessing them also change. The newer transient test methods demand turbocharging systems that provide boost air quickly and accurately, something that variable turbine technology can help to deliver.

Nitrogen Oxides

NOx is produced in the cylinder during combustion when the gas temperature exceeds 2200°C and the nitrogen in the air reacts with the oxygen. One way to reduce the combustion temperature is to slow down the combustion process by reducing the oxygen concentration. This is done by Exhaust Gas Recirculation (EGR), where exhaust gas is put back into the engine intake system (see figure 2). This means the gas in the cylinder is no longer approximately 80% nitrogen and 20% oxygen but, for example, 20% spent exhaust gas, 64% nitrogen and only 16% oxygen.

Although the oxygen concentration is lower, we still need the same mass of oxygen in order to be able to burn the same amount of fuel, so the intake air must be pressurised to a higher pressure on an EGR engine to increase the air density. This has major implications for the turbocharger, which is required to deliver a higher pressure ratio than before, demanding new compressor designs and sometimes two stage turbocharging.

However, in order for the exhaust gas to flow from exhaust manifold to intake manifold, the exhaust side must be at a higher pressure than the intake side. A variable geometry turbine is useful to vary boost pressure and turbocharger efficiency, to control the EGR flow and this is where the Holset VGT™ succeeds in the demanding heavy-duty market.
The Holset turbocompound system is also effective at ensuring EGR can occur as well as improving fuel efficiency and increasing engine power.

Particulate Matter

Unfortunately, by decreasing the combustion temperature to reduce NOx, more soot is created (see figure 3). To remove these soot particles, EGR engines often need a particulate trap in the exhaust system.

On Highway Heavy Duty emissions legislation by country and date of introduction
(US limits converted from g/hp.hr to g/kWh for comparison)

	NOx g/kW.h	PM g/kW.h	Date of introduction								
			Australia	Brazil	China	EU	India	Japan	Korea	Russia	USA
Euro 2	7.0	0.250	-	-	2005	1996	2005	-	-	-	-
Euro 3	5.0	0.100	2002	2004	2008	2000	2010	-	2005	2008	-
Euro 4	3.5	0.020	2008	2009	2010	2005	-	-	2010	2010	-
Euro 5	2.0	0.020	-	-	2014	2008	-	-	-	-	-
US04	2.7	0.130	-	-	-	-	-	-	-	-	2004
US07**	0.27	0.013	-	-	-	-	-	-	-	-	2007
US10	0.27	0.013	-	-	-	-	-	-	-	-	2010
Japan 05	0.25	0.015	-	-	-	-	-	2005	-	-	-

**US07 legislation requires that half the engines a manufacturer produces should meet the US10 NOx requirements

Fig 1 - Emissions regulations

Alternatively, engine manufacturers can choose to reduce the particulate matter in the cylinder by burning off the soot particles using high combustion temperatures, then dealing with the NOx in the exhaust system. The Selective Catalytic Reduction (SCR) method is the most popular method for this and involves optimising the engine for fuel consumption and low particulates and then using a catalytic converter in conjunction with a urea solution to convert the harmful nitrogen oxides to nitrogen gas and water (see figure 4).

Most aftertreatment systems impose a back pressure in the exhaust system that can fluctuate with time. This requires the turbocharger to be a different specification and of the highest efficiency possible and a variable turbine is useful to keep boost pressures controlled accurately.

Diverse Solutions For a Diverse World

Different engine manufacturers are using different emissions solutions, not just because the emissions legislation differs from region to region, but also due to economic and market factors. SCR systems require the diesel fuel to have low sulphur content, which isn't yet available worldwide and they also need a supply of urea solution, otherwise the system will not work and the on-board diagnostics system will reduce the engine power.

In Europe, with its high fuel costs, it is easy to justify the cost of the urea supply infrastructure as SCR engines use less fuel than EGR engines. In the USA, lower fuel prices and the difficulty of implementing the urea supply chain in a more sparsely populated country means that EGR engines tend to dominate.

Cummins is committed to creating a cleaner, healthier, safer environment through the development of engines and emissions components to meet and exceed the legislated requirements for diesel engine emissions. Cummins Turbo Technologies has a large portfolio of products produced around the world to supply each customer with the best turbocharging technology for their chosen emissions solution.

Cummins is committed to creating a cleaner, healthier, safer environment through the development of engines and emissions components.

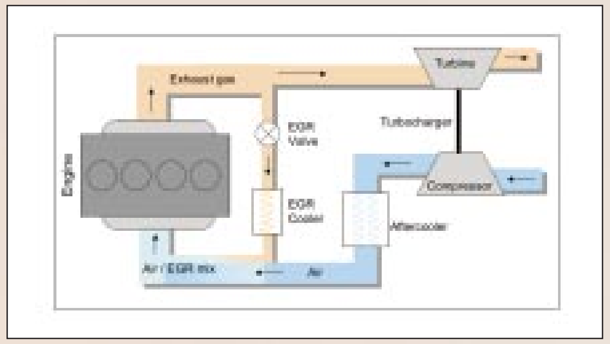


Fig 2 - EGR Engine

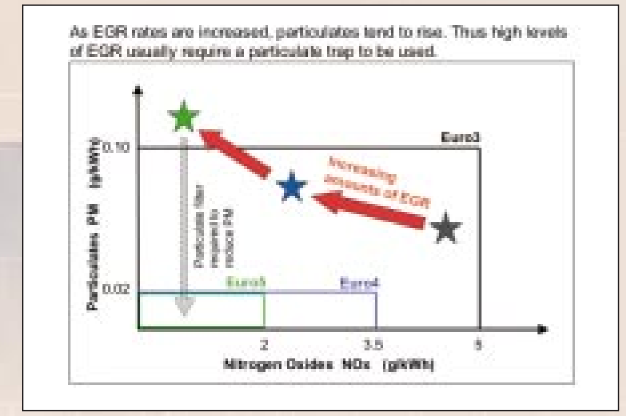


Fig 3 - The EGR route to low emissions from Euro 3 to Euro 4 and 5

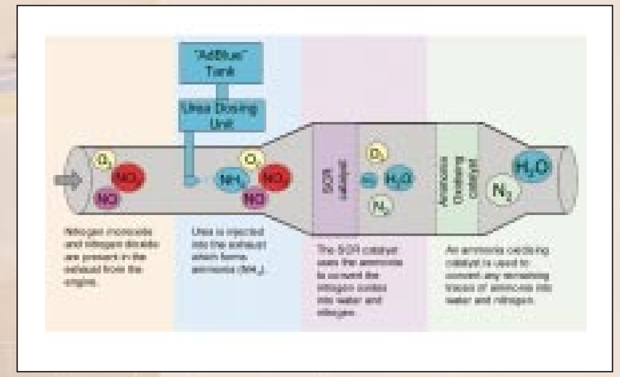


Fig 4 – SCR aftertreatment system

Advances in Turbocharger Impeller Materials

Written by Luke Hankin, Group Leader – Materials Science

As many HTi readers will appreciate, the job of a turbocharger impeller is to harness the power delivered through the shaft from the turbine stage in order to compress air from ambient to high pressure for delivery to the engine. The impeller transfers energy from the shaft to the air by forcing the air centrifugally outwards from the axis of rotation.

A radial compressor wheel can deliver a higher compression ratio in one stage of compression than an equivalent axial design. Multiple axial compressor stages of the type used in a jet engine would be needed to achieve the same performance, which in a modern diesel turbocharger calls for compression ratios up to 5:1. An image of a radial compressor or impeller and the air flow through it is shown in figure 1.

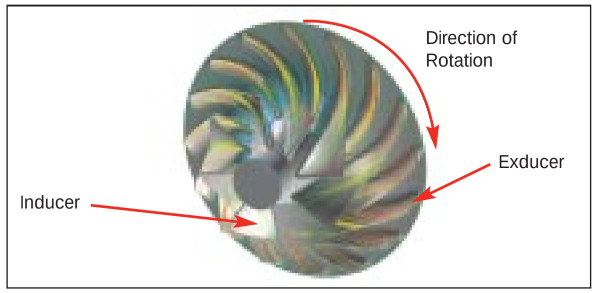


Fig 1 - Radial impeller shown with surface streak lines, showing inlet (inducer) and outlet (exducer).

The complex geometry of the impeller blades creates some unique challenges in manufacture, which has resulted in the evolution of some innovative casting techniques and alternative methods of impeller production. Selecting the best material and manufacturing methods are clearly vital considerations and can only be made after detailed assessment of individual turbocharger applications.

Impeller Operating Conditions

The primary considerations for material selection are operation temperature and durability requirements of the impeller. When air is compressed, the temperature of the air will increase. The final temperature of the compressed air will also be affected by impeller efficiency, which is kept to a maximum by optimised impeller design. Figure 2 shows that the wheel is progressively hotter towards the outer diameter of the wheel.

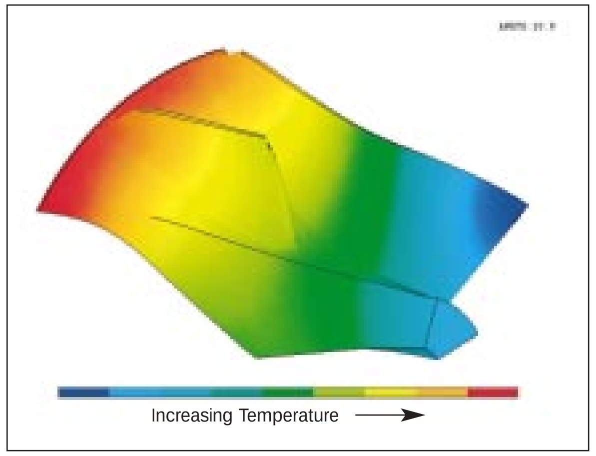


Fig 2 - Temperature distribution in a radial impeller.

Stresses are generated in the impeller due to centrifugal forces proportional to the mass of the wheel and the square of the rotational speed. Typically, the highest stresses in the impeller are generated in the bore, where the wheel is located on to the shaft and at the root of each blade as shown in figure 3. The maximum tolerable stress limit and hence 'release speed' used in designing impellers are based on the experience gained over many decades. These limits take into account temperature and time dependent material properties, as well as the effect of stress concentrations that are geometric or manufacturing process related.

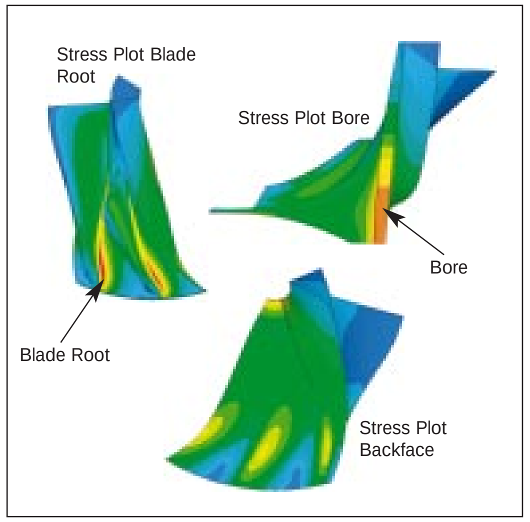


Fig 3 - Contour plot of stresses generated due to centrifugal loading, showing peak stresses in blade root and bore.

The maximum release speed of an impeller for any application is limited to a percentage of the maximum design speed depending on the 'duty cycle' of the application. For example, the release speed for a turbocharger in a city bus engine, where typically the impeller speed is constantly changing, is less than that for a generator application with near constant speed operation.

Materials and Process Selection

Cast aluminium remains the most common material used for turbocharger impellers due to its relatively high strength to weight ratio and the low resulting compressor wheel inertia.

The most common casting method for producing aluminium impellers employs a foamed plaster mould produced from a rubber pattern. This process was a development of the existing Antioch process that uses a denser plaster mould. George Gardiner and his team at Alcoa (Aluminum Company of America) developed the newer process variant in the mid to late 1950s. The use of a foamed plaster mould increases the ability to cast thin sections by drawing a vacuum through the mould. The original Cummins Inc turbocharger impellers were produced in Cleveland, Ohio by this process.

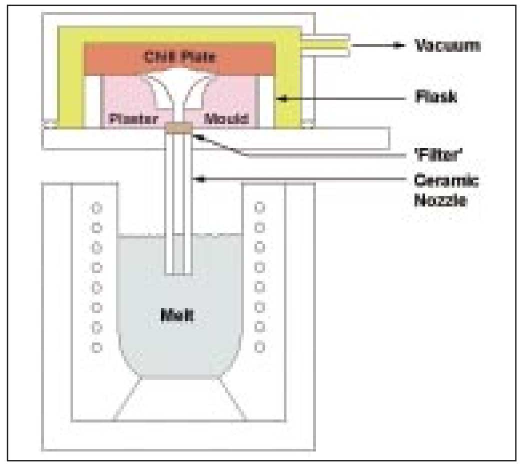


Fig 4 - Schematic of atmospheric pressure furnace configured for plaster mould casting process.

Alcoa closed its facility in Ohio in 1970 and the technology was transferred to other suppliers with the process remaining largely unchanged today.

Cast impellers are almost exclusively produced using an Al-Si-Cu-Mg aluminium casting alloy by this process using an atmospheric pressure furnace, which is shown in figure 4. The casting is produced by lowering the pressure in the mould cavity, which in turn induces the molten aluminium to fill the mould cavity under atmospheric pressure.

Pure aluminium is soft and ductile. Alloying elements are therefore added to form precipitates during subsequent heat treatment. The precipitates impede dislocation movement, which is the mechanism by which plastic deformation in metals occurs. Meanwhile silicon components improve the fluidity and castability of the alloy.

With our Holset range of turbochargers, Cummins Turbo Technologies remains the market leader in impeller design and technology.

One of the drawbacks of cast impellers is that the casting process can lead to the formation of casting defects, which can reduce the durability of the impeller. However, advances have been made in aluminium foundry technology and Cummins Turbo Technologies has pioneered the use of high resolution eddy current defect detection techniques. This has helped Cummins Turbo Technologies partner with suppliers to measure and certify improvements in the casting process using Six Sigma practices.

Second Generation Aluminium Impellers

Cast aluminium cannot normally achieve the same durability as wrought aluminium for turbocharger impellers. Wrought alloys are mechanically processed, which breaks down any defects that might be present and refines the grain structure to improve the fatigue properties. There is typically an order of magnitude difference in the grain size of cast and wrought alloys, which can be seen in figure 5. It is also possible to have a higher content of alloying elements in a wrought aluminium component, which further improves its fatigue properties.

Machined-from-solid (MFS) impellers were first introduced in Holset turbochargers in 2002 for highly cyclical applications; for example, stop-start city bus operation where there were additional durability challenges. A large percentage of Holset aluminium impellers are now MFS and are produced using state-of-the-art high speed five-axis milling machines.

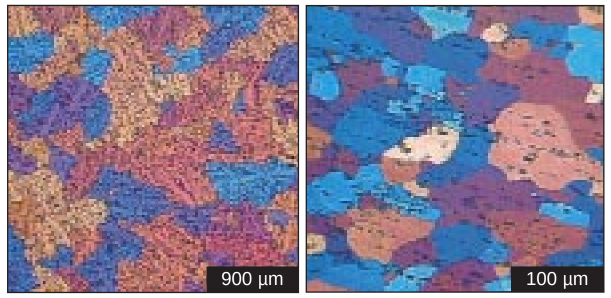


Fig 5 - Example of cast aluminium and wrought aluminium microstructure. Individual grains are observed as different colours. The magnification of the wrought alloy image is nearly ten times higher than that of the cast structure, demonstrating the finer grain detail of the wrought alloy.

Titanium Impellers for Durability at the Highest Temperatures

The application temperature limit of a cast aluminium or MFS aluminium impeller is specified in terms of maximum compressor outlet temperature. For all aluminium alloys, however, there are limits imposed on the temperature of operation due to temperature related material effects, notably softening, ageing and creep.

Extreme temperatures and stresses, especially those generated at the highest compressor ratios, can preclude the use of aluminium as an impeller material. If the compressor outlet temperature guideline for aluminium impellers is exceeded, or if the required fatigue life is greater than that of an MFS aluminium impeller, then today a titanium impeller is specified.

Back in 1996, it was Cummins Turbo Technologies that led the way in featuring a Holset HX83 turbocharger with a titanium impeller. Titanium impellers, as seen in figure 6, are made using the investment casting process. A wax pattern of the impeller is made using a steel tool and assembled on a casting tree with other waxes. The wax assembly is first coated with a proprietary ceramic face coat and subsequently with a coarse ceramic back-up coat to create a shell mould. The shell is dried and the wax melted out before the titanium is cast in a vacuum arc or induction skull re-melt furnace. The principles of the two furnace types are the same: a titanium electrode is melted under a vacuum, by striking an arc between the electrode and a cooled copper crucible and then poured into the mould.

Fig 6 - Titanium impeller

Ten years after the appearance of the first cast titanium impeller, MFS titanium impellers are being used for low volume applications or where the blade geometry is not suitable to investment casting manufacture.

With our Holset range of turbochargers, Cummins Turbo Technologies remains the market leader in impeller design and technology. New and exciting impeller manufacturing processes are already being benchmarked for use in the turbochargers of tomorrow, promising to maintain our comparative advantage.

Six Sigma

Ensuring products deliver customer requirements

Written by John Fuller,
Master Black Belt DFSS

Six Sigma has been making an impact on the efficiency of Cummins group operations since 2000. Many people in the industry will have encountered Process Six Sigma or DMAIC (Define, Measure, Analyse, Improve, Control) methodologies, either through becoming a Green or Black Belt or by being a project team member. A smaller number will be familiar with DFSS (Design For Six Sigma) though perhaps fewer will be aware of TDFSS (Technology Development For Six Sigma).

In its broadest sense, Six Sigma is a methodology for understanding variation in processes or products and defining the effect of such variations on the business. From analysis of data an approach is developed for controlling and reducing that variation. DMAIC is primarily aimed at improving existing processes and products that are not performing as well as they might. On the other hand DFSS and TDFSS are designed to implement new processes and products, which from the outset will control variation within predetermined restricted limits.

Although DFSS and TDFSS are based on similar methodologies, they are applied in different environments. While DFSS is rooted in the Value Package Introduction (VPI) process and provides the toolkit with which to achieve VPI deliverables, TDFSS performs a similar role for Product Preceding Technology (PPT). Both disciplines aim to achieve a thorough understanding of the requirements of a product or process, as they would be heard from the voice of the customer (VOC). In this context a 'customer' could be anyone coming into contact with the product or process, from purchasing managers, through to assembly line personnel and end-users. Customer information is then translated into specific, measurable, system data. A large collection of statistical tools can then be used to make key decisions in ensuring an optimised, robust design.

Both methodologies have been introduced into Cummins Turbo Technologies in recent years; DFSS in 2000 and TDFSS in 2004. DFSS is well established across the globe with 43 Cummins Turbo Technologies personnel to date having completed training. At the time of writing three more people are currently in training and there are plans for a further 16 to be trained during 2006. A total of 24 projects have been completed since 2000 and a further 30 are currently active. TDFSS is at an earlier stage of its evolution, with two people trained and two more under training. Two TDFSS projects have been completed since 2004 and three more projects are currently active.

DFSS and TDFSS have been applied to a variety of challenges within Cummins Turbo Technologies, ranging from specific product issues relating to unique customer requirements, through the development of new analysis or measurement processes, to defining best practices for designing components.

There have been several projects in these categories relating to impeller development, from aerodynamic and mechanical design refinements to meet new applications, to the evolution of new inspection processes for blade geometry and non-destructive testing of castings.

Development of new compressor cover designs, able to achieve the higher pressure ratios demanded by new automotive applications, has been the focus of several Six Sigma projects, while further programmes have led to new experimental techniques related to turbocharger bearing systems.

ADS

ADS

IMechE

Festival of Speed

Putting the company on public view

Written by Sara Walls, Communications Co-ordinator

IMechE International Conference

Cummins Turbo Technologies mounted an impressive display of Holset products and related technology at this year's Institution of Mechanical Engineers (IMechE) international conference and exhibition on 'Turbochargers and Turbocharging', held in London in May. The event covered all current aspects of design, development and application of pressure charging devices and their associated technologies. The conference was the latest in a line of successful and prestigious events organised by the IMechE every four years since 1978.

Cummins Turbo Technologies' Henry Tennant, Senior Technical Advisor, chaired the first session of the conference covering 'Compressors and Novel Intake Systems'. Later Owen Ryder, Senior Engineer, Air Handling made a presentation on 'The Design and Testing of an Electrically Assisted Turbocharger for Heavy Duty Diesel Engines'.

On the second day of the event, Xiaozhen Sheng, Senior Engineer, Applied Mechanics presented a paper on the 'Dynamics of Mistuned Radial Turbine Wheels' followed by Stuart Kitson, Chief Engineer, Turbocharger Technology whose presentation was entitled 'Improving Analysis Capability in Order to Reduce Turbine High Cycle Fatigue (HCF)'.

Following on from this, Cummins Turbo Technologies are pleased to announce that Henry Tennant and John Allport, Technical Advisor have been elected Fellows of the IMechE. This is the highest elected grade of membership within the Institute and is awarded in recognition of exceptional engineering achievements and contributions to the engineering profession.

Festival of Speed

For several years Cummins has taken part in the Goodwood Festival of Speed, held in West Sussex, UK, with the company's hospitality trailer and a display of engines. It is said to be 'the world's biggest and most prestigious historic motorsport event'.

A group of Cummins Turbo Technologies application engineers attended the event to explain the benefits and the finer points of turbocharging. Sectioned models of Holset VGT™ and Holset wastegate technology were featured on the stand, as was an industrial Cummins QSK50 diesel, a V16 of 50 litres developing 2300hp equipped with two-stage Holset turbochargers consisting of two Holset HX83 and two Holset HT100 turbochargers.

ADS International Convention

The Association of Diesel Specialists (ADS) held their 50th International Convention from 2-6 August in Chicago, Illinois. Cummins Turbo Technologies exhibit each year at the four day convention. On display were the Holset HT60 and Holset HY55V turbocharger, and the new 2007 Dodge Ram Holset HE351Ve turbocharger. In attendance from Cummins Turbo Technologies were Kenny Taylor, Aftermarket Sales Manager, Yelena Domashova, Turbocharger Product Manager and Steve Brezinski, General Manager North America and Martyn Howorth, General Manager Worldwide Aftermarket.

IAA Hanover

'The New Cummins' was unveiled at the IAA Hanover exhibition in September. For the first time at Hanover, Cummins Engines, Turbo Technologies, Filtration and Emissions Solutions products were all displayed together. The New Cummins branding strategy unites all businesses and products under the Cummins brand name. This provides a stronger, more recognisable Cummins that will be applied globally and across all business units.

The ten day event showcased all products and information from Cummins. Using the theme, 'The Right Technology Matters' the exhibition stand portrayed the message that Cummins provides a range of relevant engine technologies to the automotive industry. Turbochargers on display included the following: Holset HE221W, Holset HE351Ve, Holset HE531Ve, Holset HX82 and our Holset turbocompound unit.

IAA Hanover