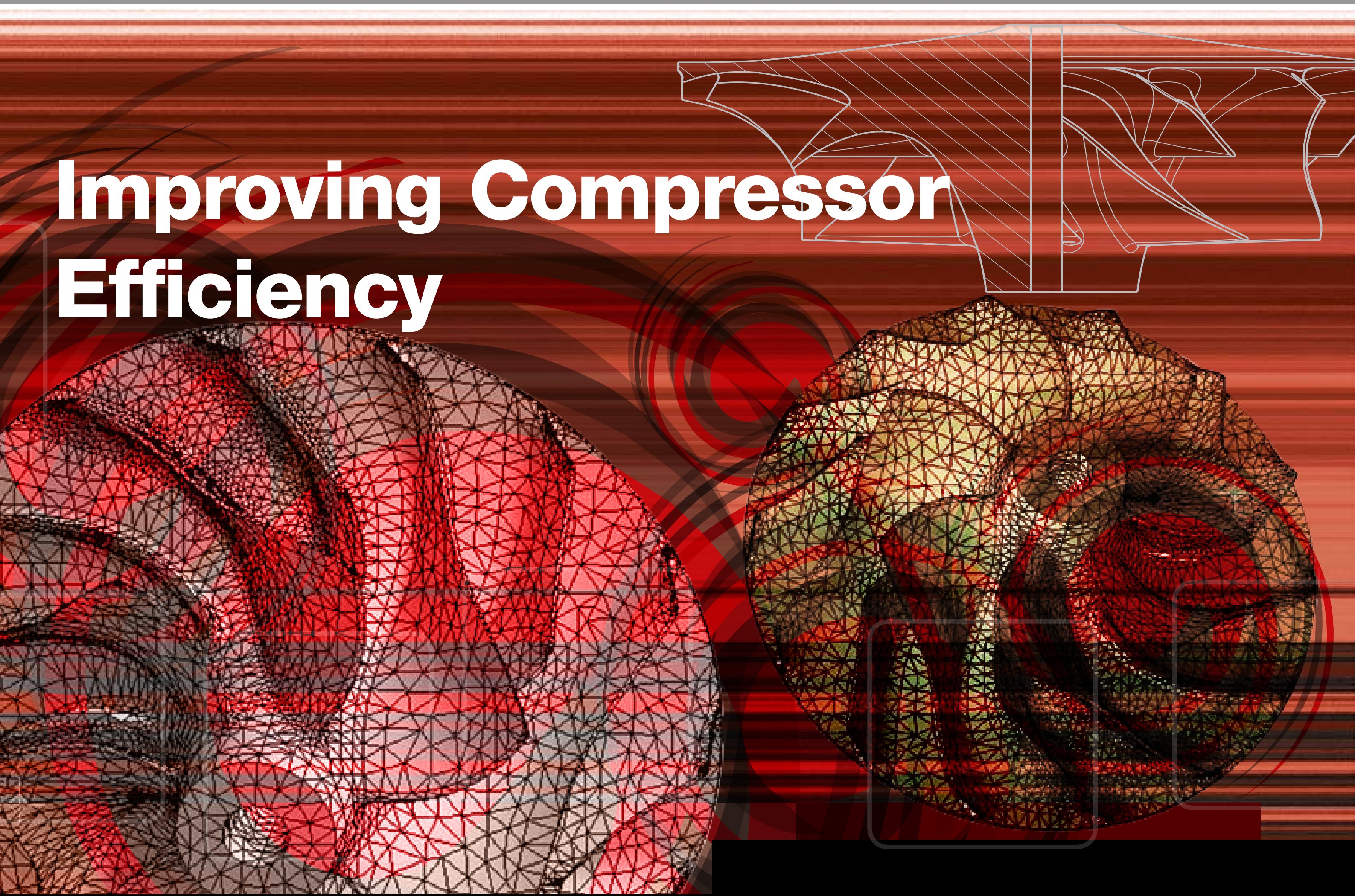
Turbo Technologies

HTi

The Latest Turbocharger News

Improving Compressor Efficiency



Edition 14:

Executive Comments

There is no denying that 2009 was a difficult year for businesses worldwide. The media labelled it "the worst global recession since the Great Depression." Thankfully, it now seems to have loosened its grip and the so-called green shoots of recovery are sprouting around the world. The extent of the revival varies country by country. It remains slow for Europe in general and for North America, but emerging markets such as China, India and Brazil are again growing vigorously.

We ensured that we were equipped with the right tools and attitude to see ourselves through the worst of the global recession. We implemented our 'Emerging Stronger Model' which involved an even sharper focus on our customers and a relentless drive for quality and breakthrough air handling technologies. It also involved some tough decisions to realign and restructure the business to aggressively reduce costs. We have focused our efforts around the major US EPA 2010, Euro V and Tier IV legislative programs, ensuring that we deliver our best-ever new product launches in all markets and provide first class early life care in conjunction with our customers.

In this issue of HTi you will find articles about some of our major new product developments, such as waste heat recovery and compressor performance improvements. We tell you about the engines equipped with our turbochargers for Euro V and US EPA 2010 emissions regulations and how we are looking post-Euro VI at our customers' needs to work in partnership to help provide products with low emissions and excellent fuel economy. We also outline our robust new product development process and the work carried out by our Advanced Engineering Department to create market-leading technologies.

Mark Firth

We are exhibiting at IAA Hannover in September this year, where we will be displaying a wide range of our technology, including variable geometry, turbocompounding and two-stage turbocharger systems. All play an important role in enabling our customers to meet strict emissions limits in even the most rigorous operating conditions.

Finally, there is a survey at the back of the magazine aimed at giving us a better understanding of your preferred method of communication. We put a strong emphasis on customer service at Cummins Turbo Technologies and want to ensure that we are doing our best to communicate what you want to know, when you want to know it and how you want to hear it. We appreciate your feedback.

Mark Firth
Executive Director; Research and Engineering

Editorial

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

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Choosing Turbochargers:
Future Powertrains

Written by Owen Ryder; Principal Engineer – Engine Air Systems

The dual demands of better fuel economy and increasingly stringent exhaust emissions limits, multiplied across a wide range of customers and applications, are driving engine and powertrain technology in different directions. Each places different demands on the turbocharging system, leading to a growing number of alternative turbocharging solutions.

This array of options makes it more difficult for an engine manufacturer to pick the best turbocharging system for a particular application. Wastegate, variable geometry, two-stage, sequential and turbocompound systems all have their merits and compromises, so choosing the best option for each application calls for considerable knowledge and analysis.

The pros and cons of the various systems are the subject of one of the papers presented by Cummins Turbo Technologies at the Institution of Mechanical Engineers (IMechE) 9th International Conference on Turbochargers and Turbocharging, held in London in May. The paper reviews each of the solutions on offer, but rather than recommend a specific solution, it suggests a good method of deciding how to evaluate which system to use.

It is not as simple as selecting an option from a chart; the choice of turbocharging system is determined by the individual application. Cummins Turbo Technologies has experience of a huge range of applications and the technologies required to deliver success to each of them. This calls for close co-operation between the original equipment manufacturer (OEM) and supplier, so we offer direct engineer-to-engineer communication, making it easier to consider complex requirements and develop the best total cost solution.

Focus on fuel economy

Recent advances in engine technology have concentrated on reducing pollutants but the focus during the next ten years or so will be on reducing fuel consumption. The solutions will have to be more radical than merely improving the efficiency of engines or components. We are likely to see new transmission systems that allow the engine to run in its most efficient condition for most of the time. As more vehicles begin to use regenerative braking as a way of capturing waste energy, this increases the likelihood of some form of electrical powertrains.

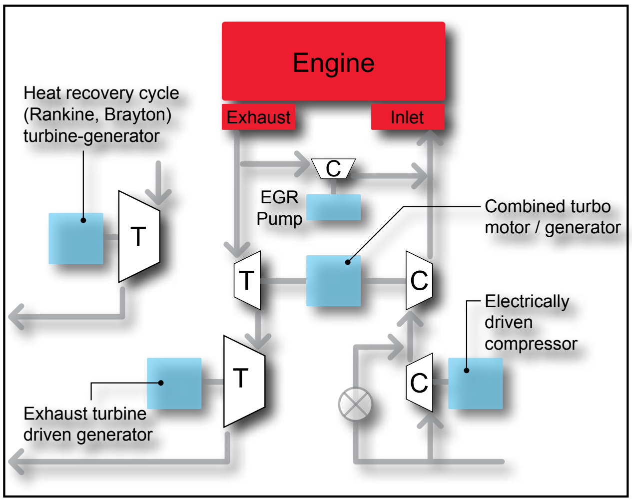


Fig 1 - Potential locations for electrical turbo devices

Extracting every possible last joule of energy from the exhaust gas will become vital and turbochargers, power turbines and waste heat recovery systems will be a key part of that process. The Cummins Turbo Technologies paper at the IMechE conference discusses a number of different options for including electric motors in turbochargers, (figure 1) either to speed up the compressor or extract power from the exhaust gas via the turbine.

No single system can be recommended 'en bloc' as the requirements of each application have a direct bearing on which system should be used. That is why the common analytical approach between engine and turbocharger manufacturer is so critical.

The next decade will be exciting in our business as turbochargers adopt new roles in evolving drivetrains. Engineers at Cummins Turbo Technologies are ready to develop the next generation of turbomachinery for the next generation of vehicle propulsion.

Recovering Waste Heat

from Heavy-Duty Diesel Engines

Written by Nick Sharp; Technical Advisor - Air Handling

Though not currently legislated, there is growing pressure to improve fuel consumption of heavy-duty diesel engines because it reduces emissions of carbon dioxide (CO_2), the most common greenhouse gas causing climate change. The emission of CO_2 is directly related to the quantity of fuel burned, so aside from the obvious financial benefits, there is an indisputable environmental motivation to reduce fuel consumption.

On a typical modern turbocharged and charge air cooled diesel engine, with a thermal efficiency of around 40-45%, the remaining 55-60% of the fuel energy supplied is lost in the form of heat. This heat is in the exhaust gases, in the engine coolant and in the charge air cooler. Clearly, if some of this waste heat can be recovered and its energy turned into useful power, it can be used to augment the engine's power output. This means we are increasing the engine's thermal efficiency and thus reducing its fuel consumption

Current waste heat recovery systems

A number of engine manufacturers have already used turbocompound systems to recover some of the waste heat in the exhaust stream. In a turbocompound arrangement a separate second turbine is placed downstream of the turbocharger's turbine, where it expands the exhaust flow to produce power. In a heavy-duty automotive diesel engine with turbocompounding, the recovered power is mechanically transmitted to the engine crankshaft. Some other diesel engine applications, such as marine, use turbine-generator systems that rely on electrical power transmission. Electrical power transmission needs no direct fixed relationship between the high rotational speed of the turbine shaft and the much slower engine crankshaft speed, so the lack of a mechanical link is clearly attractive to turbomachinery designers.

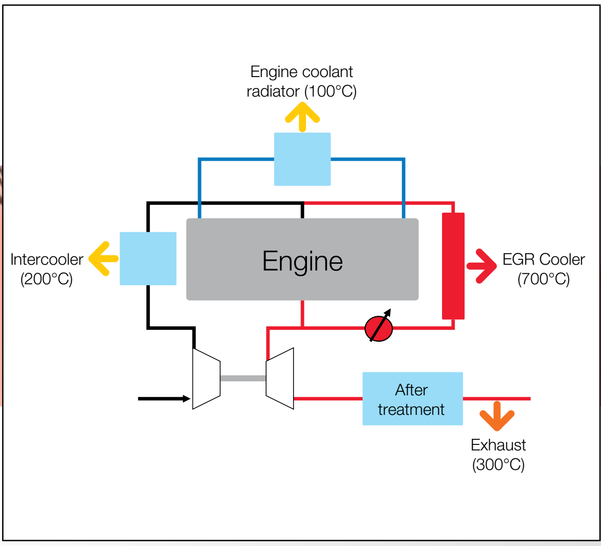


Fig 1 - Sources of waste heat and typical temperature levels

Current on-highway turbocompound systems can improve fuel economy by 3 to 5%. One challenge with conventional turbocompounding is that in order to extract the work through temperature drop in the exhaust gas, we need to expand the exhaust gas flow. The expansion process needed means the backpressure on the engine is increased, which in turn increases the pumping work. Consequently, there is always a challenge to configure the turbocompound system to give maximum gain in crankshaft power for minimal increase in pumping losses and thus fuel consumption.

Other waste heat sources

Even though 55 to 60% of the fuel's energy is theoretically available as wasted heat, the ability to use this energy to do useful work is limited by its temperature. The thermodynamic principle of exergy allows us to evaluate the useful work potential of a waste heat source and tells us that sources with high temperatures provide the greatest potential. Figure 1 shows possible sources of waste heat and their typical temperature levels.

On a modern diesel engine that uses cooled exhaust gas recirculation (EGR) to reduce oxides of nitrogen (NOx) emissions, the EGR cooler is an ideal choice for accessing waste heat because this is where exhaust temperature is highest. The lower exhaust temperature available downstream of the turbocharger's turbine means there is lower exergy, and hence less potential to extract useful work, but it has the advantage of allowing us to use the relatively simple turbocompound system.

A more sophisticated approach is needed to access the exergy available at lower temperature locations. Essentially, the heat first has to be extracted by transfer to another medium and then from this medium back to the engine.

The Rankine cycle (Figure 2) is a well documented way of accessing the waste heat from automotive and stationary engine systems. Named after the Scottish engineer and physicist James Rankine, this thermodynamic cycle is the basis of steam power plant used in electricity generation. When applying this technique to improve engine thermal efficiency, the engine's waste heat is used to boil and superheat the working fluid that is then expanded to produce useful power to augment the engine's output.

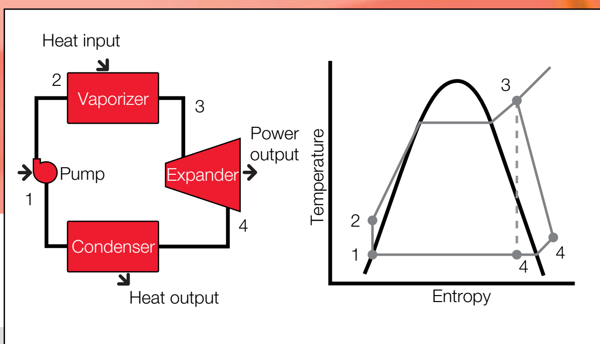


Fig 2 - Rankine cycle

The fundamental principle of using an organic fluid instead of water allows the liquid to vapour phase change to occur at lower temperatures, addressing the need to utilise alternative lower temperature heat sources. In the case of heavy-duty diesel engines, this organic Rankine cycle (ORC) allows heat energy to be extracted from relatively low temperature sources like the exhaust downstream of an aftertreatment system and even from the charge air cooler.

The working fluids, their associated ORC operating parameters and the engine system architecture all impact on the choice of the machine used for the expander. Current experimental systems provide evidence gathered from a variety of positive displacement machines and turbines. There is naturally some synergy for Cummins Turbo Technologies between current turbocharger architecture and a turbine for a waste heat recovery Rankine cycle.

Cummins Turbo Technologies are currently researching an organic Rankine cycle turbine expander. Intended for use on an engine system with mechanical power transfer, the demonstrator unit shown in Figure 3 uses an impulse axial turbine rotor to recover the power from superheated refrigerant vapour. The recovered power is transmitted via a hermetically sealed magnetic coupling to a pinion gear. Like a conventional exhaust gas power turbine, the pinion gear transmits power via a gearbox back to the crankshaft. Unlike a conventional power turbine, the seal/magnetic coupling arrangement is necessary to prevent the high pressure organic refrigerant escaping to atmosphere.

Both mechanical and electrical systems have been used to transmit the recovered energy back to the engine crankshaft. Without a direct mechanical link to the engine crankshaft, a high power density electrical machine would suit the turbine's high rotor speed. We can use the knowledge of optimum rotor speed to select the most suitable turbomachine, which is most likely to be either an axial or radial inflow turbine.

Compared to a standard turbocharger, there are additional design challenges for the ORC turbine. Two-phase flows (liquid and vapour) are known to give big erosion problems on Rankine cycle turbine blades and sealing is an issue because leakage cannot be tolerated: high system pressure must be maintained and loss of organic fluid is unacceptable for environmental reasons. Nevertheless, it is worth persevering to overcome these issues. ORC systems on heavy-duty diesel engines (as shown in Figure 4) have recently demonstrated fuel consumption improvements of 8%.

Fig 3 - Demonstration unit

Alternative types of waste heat recovery

Staying with thermodynamic systems, the waste heat could be used to provide power input to a cycle using air as the working fluid. A Brayton (simple gas turbine) cycle system uses an environmentally friendly working fluid and gives us the opportunity to utilise known air turbomachinery hardware. However, it is difficult to make the heat exchanger small enough to satisfy the packaging requirements of an automotive diesel engine application.

Although they have no synergy with turbocharger technology, thermoelectric systems are of interest and offer the advantages of extracting energy without moving parts, although the material technology poses many challenges.

Looking ahead

All the systems discussed, thermodynamic or otherwise, must overcome some significant hurdles. They will have to prove themselves capable of recovering waste heat in a reliable, durable and cost effective way. They will also need to be tightly packaged because they will have to be integrated into vehicle architectures similar to today's. Cummins Turbo Technologies believes there are opportunities for turbocharger-like hardware to be used as the power recovery turbine on such thermodynamic systems and continue to research this technology.

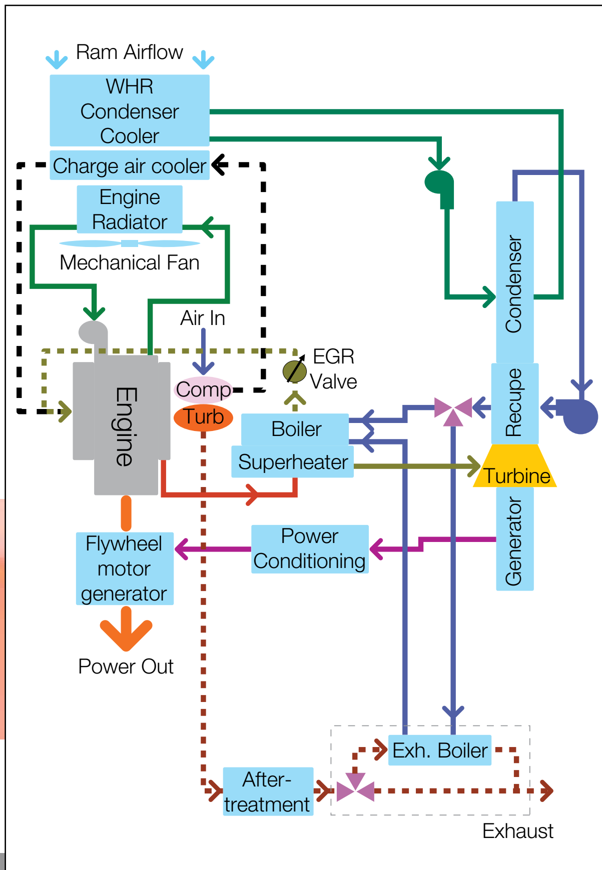


Fig 4 - ORC system on heavy-duty diesel engines

Image supplied courtesy of Paccar

A Showcase of Holset Turbochargers

for Euro V and US 10

Written by Jim Olmstead; Manager - Application Engineering (North America) and Dr John Clark; Manager - Application Engineering (Europe)

On-highway heavy-duty diesel engine emissions legislation the world over is getting progressively tougher. The pace of change is relentless and Cummins Turbo Technologies is deeply involved in helping our customers comply with the latest limits. Here we showcase our latest applications for newly released engines across North America and Europe.

North America

In January 2010, just three years after the previous limits took effect, the USA and Canada implemented the latest and most stringent national emissions limits to be found anywhere in the world.

These new Environmental Protection Agency regulations, US EPA 2010, include a nitrogen oxides emissions limit of just 0.20 g/hp-hr. The particulate matter limit is set at 0.01 g/hp-hr. Engine manufacturers that use Holset turbochargers are commonly using cooled exhaust gas recirculation (EGR) combined with selective catalytic reduction (SCR) and a diesel particulate filter. However, customers are taking different turbomachinery approaches in order to meet these new emissions standards, while also providing improved performance, fuel economy and durability.

Customers including Cummins and Volvo Powertrain are using the electrically actuated Holset VGT™. Daimler's North American engine business, Detroit Diesel Corporation, on the other hand, is using our turbocompound configuration to meet its needs.

Variable geometry

Cummins uses the 300 series electrically actuated Holset VGT on its 6.7 litre ISB engine. Different versions of the 400 series electrically actuated Holset VGT are used on larger Cummins engines: the 8.3 litre ISC, the 8.9 litre ISL and both the 11.9 and 15.0 litre ISX engines. The 400 series electrically actuated Holset VGT is also used by Volvo Powertrain on its 11 and 13 litre engines, while the 500 series electrically actuated Holset VGT is used on Volvo's 16 litre engine.

All three of these turbochargers are from Cummins Turbo Technologies' range of Holset VGTs. They are used not only to manage the airflow through the engine in fired mode and in engine braking mode but also to support the additional emissions aftertreatment systems. In fired mode the Holset VGT provides boost air and allows the engine to manage the flow of cooled exhaust gas that is fed back into the cylinders by the EGR emissions control system. In engine braking mode the Holset VGT is used to generate boost while also restricting the exhaust to provide resistance. Finally, the Holset VGT is also instrumental in the engine's management of the exhaust aftertreatment systems that contribute to the overall engine system emissions control.

Turbocompounding

Daimler's Detroit Diesel US 2010 engines use a turbocompound system that combines a 500 series fixed geometry turbocharger and an 800 series power turbine. The waste exhaust gases from the turbocharger are fed to the power turbine that is in turn connected to the engine's crankshaft via a sophisticated gearing system. This means that energy in the exhaust that otherwise would be wasted is extracted to supplement the engine's output. The turbocharger and the power turbine are carefully matched so that the system helps to drive the cooled EGR as well as enhance fuel economy by extracting the most from the fuel burned in the engine.

Fiat Powertrain use a combination of wastegated and variable geometry turbochargers in order to meet the Euro V emission limits. They opt for Holset VGTs on their higher power ratings because they increase the available air in the engine, enabling greater power to be obtained without increasing the engine's displacement.

The emissions story does not stop with implementation of Euro V in 2009, nor with the arrival of the US EPA 2010 legislation in North America earlier this year. Cummins Turbo Technologies continues to work actively with our customers to meet the demands of emissions legislation anywhere in the world. Our next big target for truck and bus heavy-duty diesel engines is the Euro VI standard, due to come into force for new type approvals in January 2013. Euro VI demands further big cuts in both oxides of nitrogen and particulate matter, so our turbochargers will be part of the solution, no matter which strategies our customers choose.

Europe

Ever tightening emissions legislation continues to drive heavy-duty diesel engine development in Europe too. The first stage of the legislation, Euro I, was implemented back in 1992. Euro II took effect in 1995, followed by Euro III in 2000 and then Euro IV in 2005. The latest standard, Euro V, was implemented for new engine production in October 2009.

Compared with Euro IV, the particulate matter limit is unchanged at Euro V, remaining at 0.02g/kW-hr. However, Euro V cuts the oxides of nitrogen limit by more than 40%, taking it down from 3.5 to 2.0g/kW-hr.

As in North America, not all the engine makers who are supplied by Cummins Turbo Technologies are adopting the same strategy to comply with Euro V limits. Some, including Volvo Powertrain, are using our wastegate turbochargers in combination with additional exhaust aftertreatment. Others, such as Scania, are using electrically actuated Holset VGTs on engines to drive EGR. Fiat Powertrain is using both wastegated and pneumatically actuated Holset VGTs.

Selective catalytic reduction

Volvo Powertrain chooses the series 500 wastegated turbochargers for its 11 and 13 litre engines. Its 16 litre engine, rated at up to 700hp, uses a uniquely tailored and larger 500 series wastegated turbocharger. In each case there is a SCR aftertreatment system in the exhaust to cut oxides of nitrogen. Using an aftertreatment system to handle the reduction of oxides of nitrogen allows Volvo to optimise its combustion and engine management for minimum particulate levels. So far, Europe has been more willing to accept the use of these SCR aftertreatment systems than has North America. This is related to the provision of the infrastructure needed for the supply and distribution of the reductant fluid (called AdBlue in Europe and diesel exhaust fluid in North America) that is needed to keep SCR systems working.

Airflow management

Scania uses a 400 series electrically actuated Holset VGT on its five cylinder 9 litre engine and a 500 series electrically actuated Holset VGT on its six cylinder 13 litre and 16 litre V8 engines. These turbochargers are being used by Scania to manage the engine's airflow, just like some of our North American customers mentioned previously.

Image supplied courtesy of Volvo

New Product Development:

Examining the Art of the Possible Whilst Imagining the Future

Written by Ram Gokal; Director – Advanced Engineering

Cummins Turbo Technologies uses two main processes to develop new products and technology. The first is called Product Preceding Technology (PPT) and is used to validate the new technology that underpins the product. The second process is Value Package Introduction (VPI). This is used to validate the technology as it is incorporated into the finished product. Although both processes exist independently of each other, they are also linked and to some extent, overlap. Both use a system of 'gates' that define the various stages of the development process: the project must pass successfully through each gate before moving to the next stage.

Product Preceding Technology (PPT)

In the PPT process (as shown in Figure 1) our Technology and Advanced Engineering functions have scope to develop an idea and prove its worth to the organisation or to a customer. This can loosely be defined as 'examining the art of the possible whilst imagining the future'.

At this very early idea stage of a project we have two gates, termed E-1 and E0. These are the first two stages before the formal start of a project. At this point, free thinking engineers can provoke engineering debate and explore new ways of doing things. Having come to some rational engineering decisions they then explain their idea or invention to engineering leaders.

The next gate, G0, marks the formal start of the project. This is when the goals and targets are set. The bulk of the Advanced Engineering and Technology work lies between G1 and G3. By G1 the concepts have been selected and we begin to understand the interactions between engineering, manufacturing and external suppliers. The objective is to ensure that the

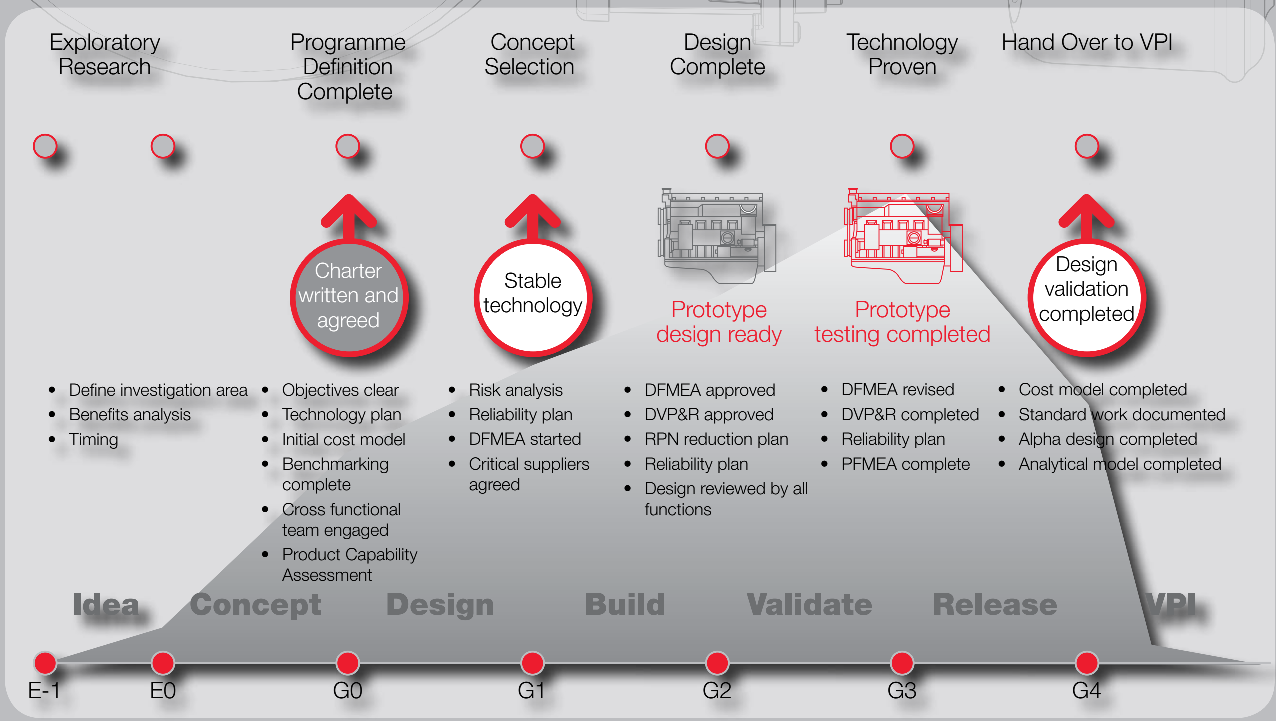


Fig 1 - Cummins PPT Process: Overview

design is feasible and can be engineered. By G2 the design is complete and the manufacturing risks assessed. The first prototype is produced. Then comes the validation stage when a re-assessment of the product is made, based on the original goals set at the outset, G0. At this point we are in a position to discuss the new product and its development with our customers.

The programme completes the PPT stage at G4 and is ready to make the transition to VPI. The Advanced Engineering and Technology functions conclude their work on the project by reporting on what has been achieved and the success of the programme up until that point.

Value Package Introduction (VPI)

The emphasis of the VPI process (as shown in Figure 2) is on making the product and on how the customer will use it. This takes product design closer to the business objective 'to meet the customer's demands by supporting the business's needs'. During VPI the focus of the validation work moves on to encompass the final product, the capability of our suppliers and that of Cummins Turbo Technologies' own manufacturing function.

Just like PPT, the VPI process is split into stages, each marked by gates. The gates start at M0 and progress beyond that point can be driven only by customer demand. However, the product inputs may be from either a PPT programme or drawn from a similar product used as a basis to evolve a new solution to the customer's requirements. As this is now a customer-driven programme it is especially important to ensure that its development and application sign off are robust. The structure of the VPI process and the controls built into each stage support that aim.

As can be seen in the accompanying figure, the bulk of our internal work is between M0 and M2. This part of the process involves intense liaison with the customer to ensure the product design meets the requirements in terms of its engineering specification and how it is packaged to fit the application. These aspects of the design are validated at M3, applying the sign off criteria that were drawn up and agreed earlier in the process for this alpha system build. From M4 onwards the focus moves from design robustness to product robustness. We define the repeatability of the design and its manufacturing capability. M5 marks the point at which limited production begins.

PPT and VPI, both immensely thorough new product development processes, leave nothing to chance when it comes to ensuring that we have a robust product.

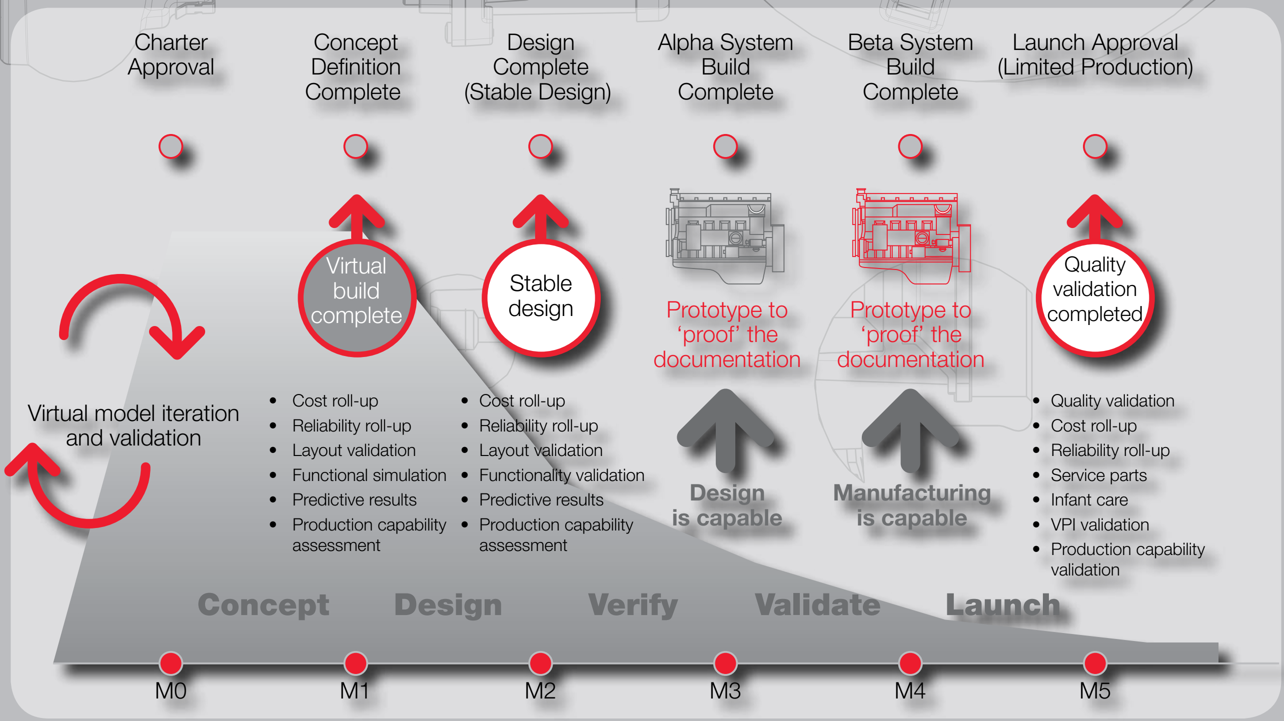


Fig 2 - Cummins VPI Process: Overview

Three Dimensional Inverse Design:

Improving Compressor Efficiency

Written by Dr Bahram Nikpour; Principal Engineer - Air Handling

The efficiency of a turbocharger has a direct influence on an engine's fuel consumption. The more efficient the turbocharger, the lower the work done by the engine during the pumping cycle, resulting in better engine brake specific fuel consumption (BSFC).

A turbocharger's overall efficiency is the product of its compressor, turbine and rotor system efficiencies:

Overall Efficiency = *Compressor Efficiency* X *Turbine Efficiency* X *Rotor System Efficiency*

Compressor efficiency therefore has a direct impact on engine BSFC and is one of the areas recently targeted by Cummins Turbo Technologies for improvements.

Optimising the design of the wheel in this way improved the efficiency of the compressor stage by up to three percentage points

This article describes the application of a 3D inverse design method using TURBOdesign-1 to design the shape of a centrifugal compressor wheel.[1] Optimising the design of the wheel in this way improved the efficiency of the compressor stage by up to three percentage points.

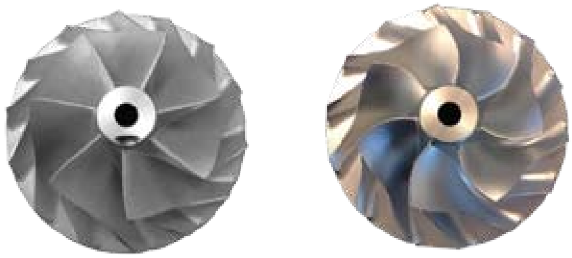
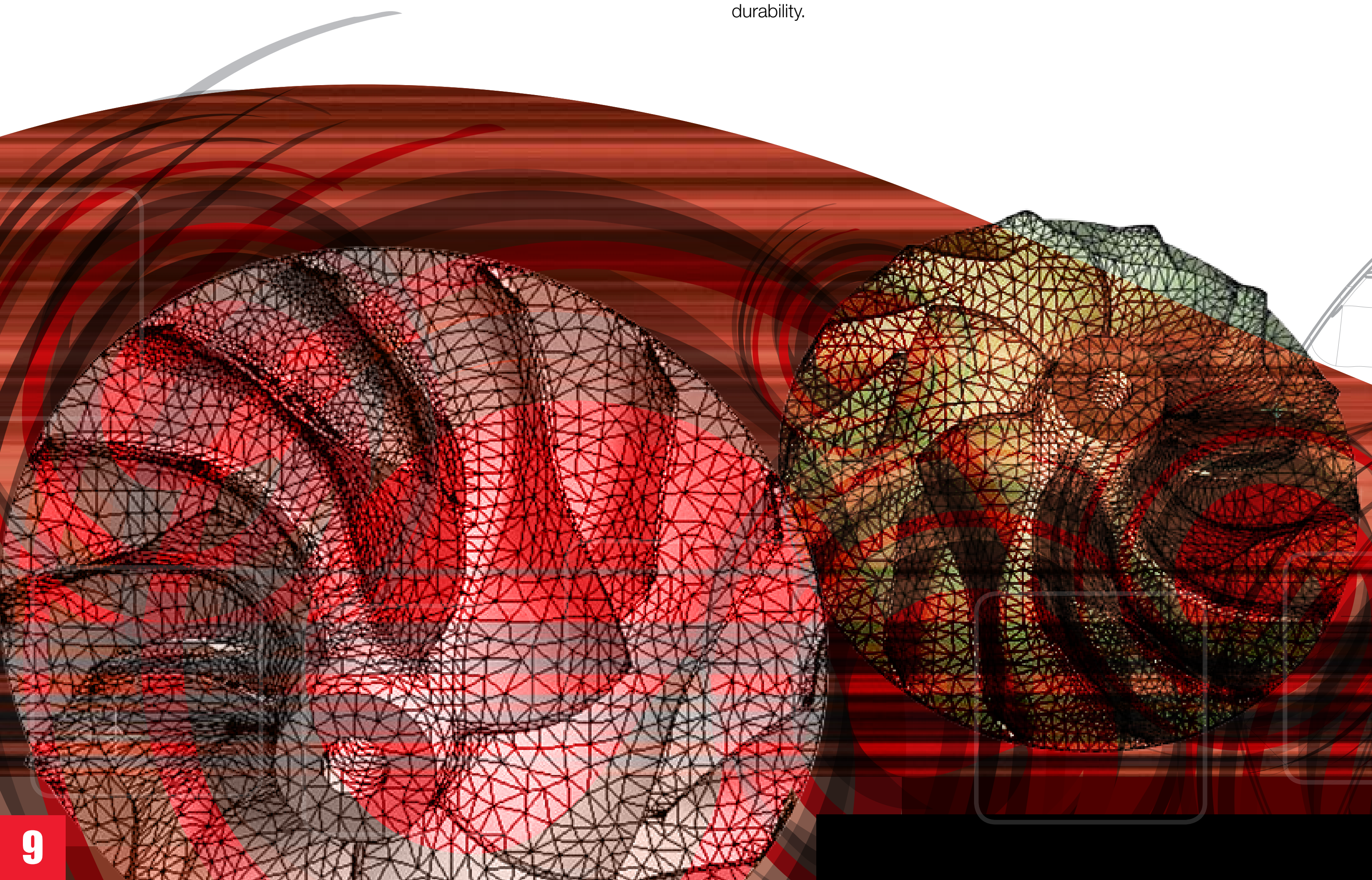


Fig 1 - Standard design *Inverse design*

What is inverse design?

Conventional design involves specifying the blade angle and thickness distribution for the compressor wheel blades and then using an iterative approach to arrive at the optimum design. Computational fluid dynamics (CFD) analysis is used to evaluate the compressor wheel's performance and finite element analysis (FEA) is used for durability assessment.

Using the alternative three dimensional inverse design method the blade geometry is computed for a specified pressure distribution along the blade surfaces.[2] CFD tools are once again used to assess performance and FEA analysis to optimise durability.



CFD analysis

Cummins Turbo Technologies uses the latest CFD modelling techniques to assess the performance of design iterations, so we are able to predict the effect of this new approach to compressor wheel design. Figure 2 shows the CFD mesh used, with the inlet section removed to reveal the compressor wheel model in detail. The CFD model was highly detailed, containing around seven million computational cells.

Performance improvement

The difference in the performance of the conventionally designed compressor stage and the new inverse design version is shown in Figure 3. This is a performance map overplot showing the difference in the two designs' compressor pressure ratio and normalised efficiency plotted against flow rate. It shows that the compressor wheel created by use of inverse design delivers measurably better efficiency. In the areas of darkest orange on the map compressor stage efficiency is 3% higher.

Availability of inverse design compressors

Currently this technology is in the research and development phase but is intended to be ready for production in 98, 92 and 85mm impeller sizes by 2013.

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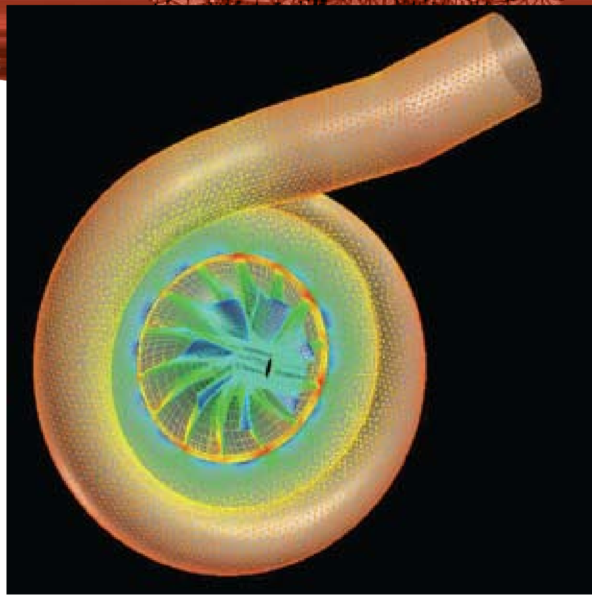

Fig 2 – CFD computational mesh

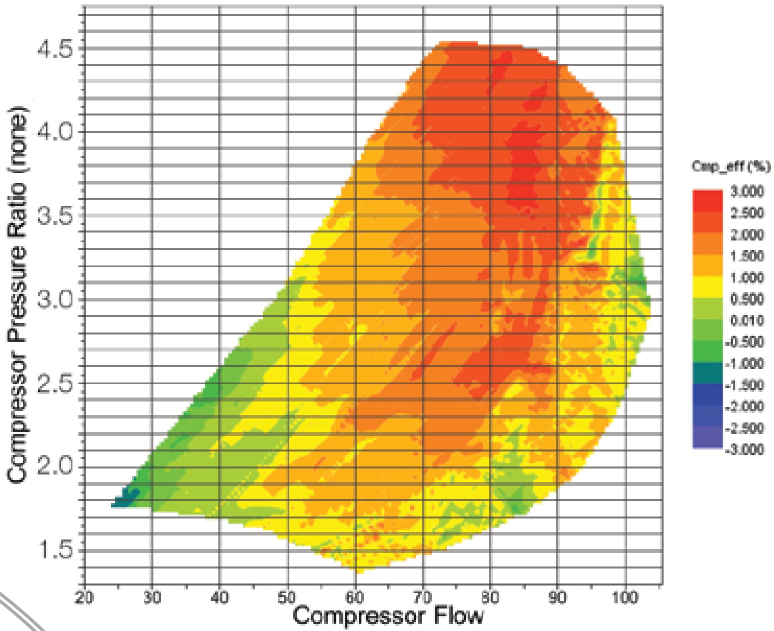

Fig 3 - Efficiency improvement with inverse design compressor

Turbo
Technologies

Our Philosophy

We enable our customers' success through our expertise, dependability and responsiveness.

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.

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