



**Turbo  
Technologies**



**The Latest Turbocharger News**

# **Smart Thinking Behind Latest Holset VGT™ Actuators**



## **EDITION 10:**

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When One  
Turbocharger  
Just Isn't Enough



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The European  
Truck Market



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# Executive Comments

In edition 8 of HTi we announced that Cummins Turbo Technologies was acquiring the 50% stake held by our joint venture partner in our Indian facility. Now, in edition 10, we are proud to announce that our Indian strategy is taking another major step forward in the shape of a second and entirely new plant in Pithampur. This world-class manufacturing facility brings the number of Cummins Turbo Technologies locations to seven, building on our existing presence in Brazil, India, UK, USA and our joint venture in China.

The growth in the vehicle market in India is plain to see and easy to understand but it was no easy matter to read the European truck market in 2007, which was the first full year of Euro IV exhaust emission limits. This new emissions legislation was just one of the factors that made last year so unusual in a European truck business that struggled to keep pace with booming demand in eastern Europe. In this issue of HTi, we analyse last year's European truck sales data and hear what truck manufacturers are forecasting for 2008.

It is almost 10 years since the introduction of the Holset VGT™. Cummins Turbo Technologies has not rested on its laurels since then and has continued to develop the Holset VGT, taking it from pneumatic to electric actuation. Now we have the 'smart' electronic actuator, the latest chapter in the Holset VGT story. In these pages we describe how smart actuation works and the benefits it delivers. Just one of those benefits is the ability to record huge amounts of information about an in-service actuator's performance. This makes fault identification and diagnosis far easier than ever before and is revolutionising the work of our Service Engineers.

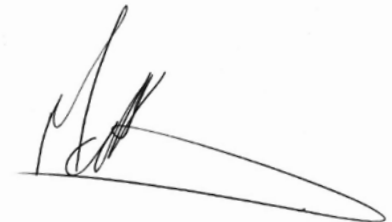
Two stage turbocharging systems have been around for many years but recently these are becoming more popular as a result of increasing demands by engine users and emissions legislation. In this edition of HTi we examine the merits of these systems and how Cummins Turbo Technologies recommends different solutions for the diverse range of applications our industry requires.



Mark Firth

The link between turbocharging and vehicle braking is probably not immediately apparent to all but is surprisingly strong. We explain why the Holset VGT is particularly effective in boosting the braking torque of an engine brake.

Finally, we discuss how Cummins Turbo Technologies uses Customer Focused Six Sigma (CFSS) methodology to increase our focus on business improvements that are highly relevant to our customers. After carrying out 30 CFSS projects over the last 2 years we are committed to completing many more this year. Working in partnership with our customers, these projects will deliver tangible benefits and will strengthen our relationships.



**Mark Firth**  
Executive Director; Research and Engineering

## Editorial

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# New Facility to be Opened in Pithampur, India

Written by Jodie Stephenson; Global Marketing Manager

**Cummins Turbo Technologies has announced that they are to open a new world class turbocharger manufacturing facility in Pithampur, Madhya Pradesh, India. This new chapter in the history of Cummins Turbo Technologies was marked with a ground breaking ceremony on 12 December 2007.**

Jim Lyons; President, Glyn Price; Vice President and General Manager, China and India and Nitin Mantri; Country Manager, India, participated in the ceremony, which was also attended by senior government officials and Anant Talaulicar; Managing Director and Chairman; Cummins India.

This announcement comes as a further move in Cummins Turbo Technologies' strategy of expanding its interests in India, following the acquisition of the remaining 50% stake from its joint venture partner last year.

Glyn Price commented on the new facility, "Pithampur will be the equal of any Cummins Turbo Technologies manufacturing facility anywhere in the world. We are proud of our operations in India. Our facility in Dewas has expanded and is now operating at full capacity. Pithampur will work in tandem with Dewas to enable the company to better meet demand from the domestic as well as global markets."

The US\$22 million capital investment in a new 80,000 sq ft purpose-built facility will create over 300 new employment opportunities and expand Cummins Turbo Technologies capacity substantially whilst allowing room for further expansion.

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**Pithampur will work in tandem with Dewas to enable the company to better meet demand from the domestic as well as global markets.**

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*Artist's impression of the new Pithampur facility*



*Attendees at the ground breaking ceremony*



*New facility ground work begins*

The new facility will be located within a Special Economic Zone (SEZ) in Pithampur, which is approximately 70km away from our existing facility in Dewas. The new facility, whilst interacting closely with the existing plant, will be a stand alone facility and will focus on manufacturing high-horsepower turbochargers for both domestic and global markets. Construction of the new plant began in January, with production set to commence in the third quarter of 2008.

The addition of a new facility will bring Cummins Turbo Technologies number of worldwide manufacturing locations to seven, building on its existing presence in Brazil, India, UK, USA and its joint venture in China.

# Two-Stage System

## When One Turbocharger Just Isn't Enough

Written by Owen Ryder; Principal Engineer, Engine Air Systems

**Owen Ryder examines the merits of two-stage and sequential turbocharging, explaining why modulated two-stage technology looks particularly attractive.**

Engine air-handling systems are becoming increasingly complex in order to satisfy the demands of tighter exhaust emission standards and enhanced engine performance. The capability of the turbocharger is critical to the success of the engine and so this has led to the development of variable turbines and the use of specialist materials for turbocharger components such as impellers.

As well as meeting emissions legislation, engine manufacturers strive to design engines that offer not only a wide peak torque plateau for good acceleration and driveability but also are capable of high engine speeds that produce more power. This is particularly relevant for light-duty vehicles that need to cruise at high speed but have fewer gears than a heavy-duty truck.

Increasingly stringent exhaust emissions legislation means that combustion must be cleaner than ever throughout the engine speed and load map and this drives the need for high turbocharger boost pressure to be available right across the engine speed range. So tough are the latest requirements that they are beyond the scope of a single turbocharger, no matter how sophisticated it may be. This is leading to the emergence of several two-stage and sequential turbocharging systems.

### Two-stage systems

Conventional two-stage turbocharging employs two turbochargers working in series at all times. True sequential turbocharging switches turbochargers in and out of use as required but they are normally connected in parallel. A modulated two-stage system brings some of the benefits of each of these two approaches. At low engine speeds it works as a two-stage system, delivering high boost pressure despite the low engine speed. At high engine speeds it bypasses the small, high pressure (HP) turbocharger allowing the bigger, low pressure (LP) turbocharger to work on its own and produce the higher flows at high engine speed.

Figure 1 shows the layouts of a) single-stage, b) two-stage, c) sequential and d) modulated two-stage systems.

Figure 2 shows the performance characteristics of these systems. The single-stage system (a) will be used as the base for our comparisons. On the two-stage map (b), the red line represents operating points on the high pressure compressor and the pink line shows the points on the low pressure compressor. The brown line is the product of these, which is the system's overall boost curve. Sequential turbocharging (c) uses only one turbocharger at low engine speeds, shown by the light blue line and two compressors in parallel at higher engine speeds, giving an apparent map represented by the dark blue lines. With modulated two-stage (d), the high pressure compressor (red), operates at low engine speeds in combination with the low pressure compressor to produce high boost pressures. At higher engine speeds, the high pressure compressor is switched out and the low pressure compressor (pink), does all the work. The resulting total boost curve (green) shows high boost pressure at low engine speeds and a high flow rate at high engine speeds.

Figure 3 compares the boost pressure curves of the four different systems. The extra boost pressure produced by a two-stage system compared with a single turbocharger is obvious. Also apparent is the wider flow range of the sequential system compared with a single turbocharger. The distinctive shape of the curve for modulated two-stage turbocharging shows the high boost pressure needed at low engine speeds and the high flow range needed at high engine speeds.

Incidentally, these two-stage systems should not be confused with twin-turbocharger systems, where two conventional turbochargers each supply half the engine.

### Which one should we use?

Conventional two-stage turbocharging is most beneficial for applications that need high altitude capability because the low pressure turbocharger can compensate for the loss in ambient pressure without over speeding.

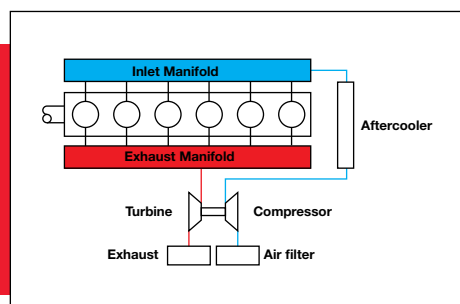


Fig 1a - Single-stage system

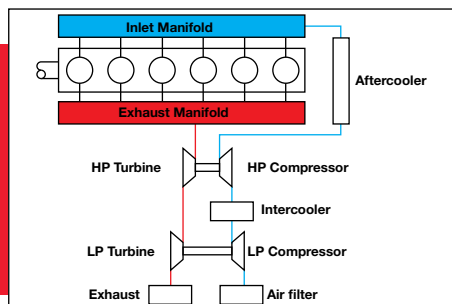


Fig 1b - Two-stage system

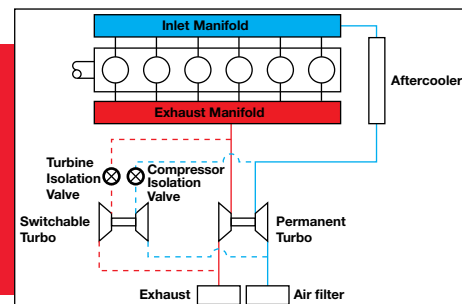


Fig 1c - Sequential system



Sequential systems are good for extending the flow range but do not deliver a higher boost pressure. These systems are ideal for passenger cars or turbocharging gasoline engines but are not appropriate for high output diesel engines.

Modulated two-stage systems offer the benefits of both high boost pressure and wide flow range, mainly due to the fact that two compressors are used. Using two compressors replicates the effect of a variable compressor without the need for a complex mechanism in the compressor housing.

The modulated two-stage system can have a high pressure turbocharger far smaller than that of a conventional two-stage system, improving transient performance by reducing the turbo lag that affects both driveability and emissions.

## Handling EGR

A growing number of engine manufacturers regard modulated two-stage turbocharging as an attractive solution. When USA's EPA 2010 and Euro VI emissions legislation comes into force, many more of these modulated systems will be used to maintain good performance.

Most diesel engines will use exhaust gas recirculation (EGR) by 2010 and so any new turbocharger system must be compatible with EGR. Engines with EGR require higher boost pressure in order to supply the engine with recirculated exhaust gas as well as the fresh air required for combustion. This higher density intake air has to be generated by a high boost pressure, as supplied from a two-stage turbocharging system.

Light-duty vehicle certified applications may not need EGR at full load due to the transient nature of the approval test cycle but any engine that requires dynamometer certification will certainly use EGR at full load. This entails being able to control turbocharger efficiency as well as achieving high boost pressures. High turbocharger efficiency is required at mid and high engine speeds to provide good fuel consumption and to assist clean combustion. However, when engine speeds are low but engine load is high it is difficult to recirculate exhaust gas because the inlet manifold pressure is higher than the exhaust manifold pressure. By using a variable geometry turbocharger as the high pressure turbocharger, the closed down turbine nozzle at low engine speeds lowers turbine efficiency, thus setting up the correct pressure difference across the manifolds to allow the exhaust gas to flow into the inlet manifold. This solution may alleviate the need for an intake throttle or a long route, low pressure EGR system.

Cummins Turbo Technologies has developed a range of technologies including two-stage and modulated two-stage turbocharging. They allow us to provide the extra boost needed by engine and vehicle manufacturers, whatever their EGR strategies, control systems and packaging constraints.

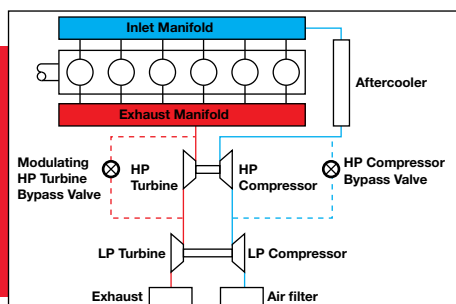


Fig 1d - Modulated two-stage system

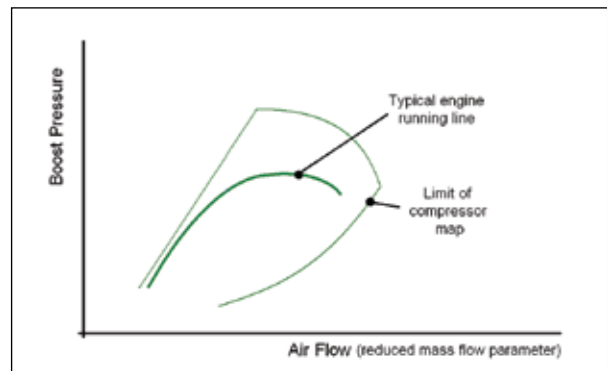


Fig 2a - Single-stage map

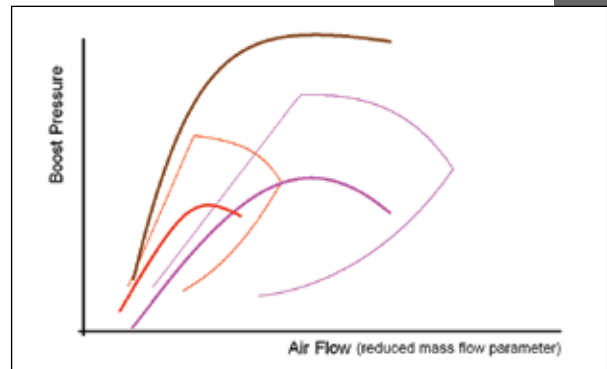


Fig 2b - Two-stage maps

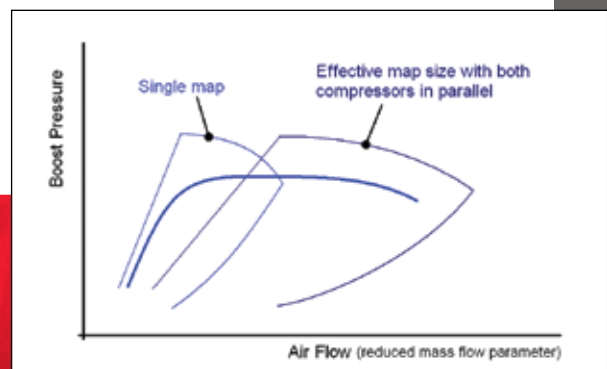


Fig 2c - Sequential effective map

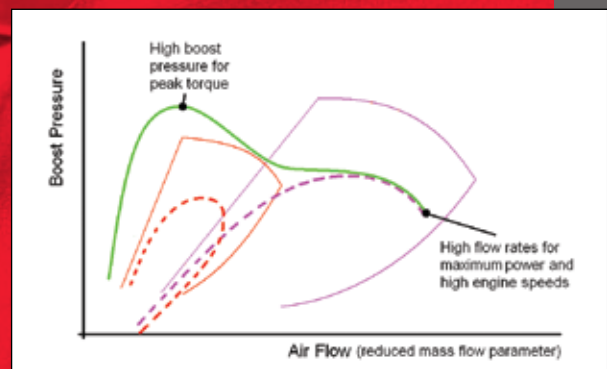


Fig 2d - Modulated two-stage maps

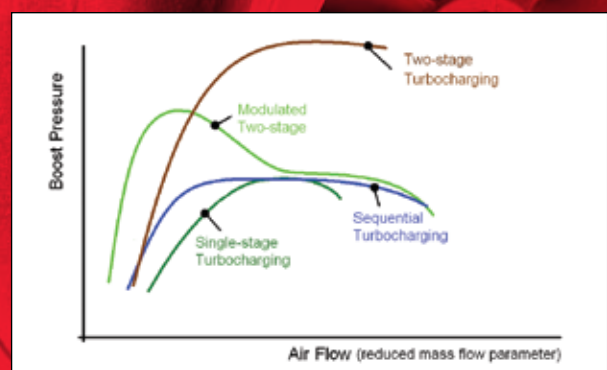


Fig 3 - Comparing boost curves

# The European Truck Market

## 2007 - 2008

Written by David Wilcox; Deputy Editor of Transport Engineer magazine

**In the last edition of HTi, David Wilcox looked at the USA market and how the recent introduction of the next round of emissions legislation, EPA 2007 has affected the heavy-duty diesel market place. Continuing his look into the worldwide truck markets, David now focuses his attention on the European truck market and recent changes in the emissions legislation in Europe.**

2007 was the first full year of Euro IV, the European emission legislation for heavy-duty diesel engines. Euro IV trucks cost more and feature additional emissions reduction technology; either selective catalytic reduction (SCR) or cooled exhaust gas recirculation (EGR) plus a particulate catalyst/filter in the exhaust. Yet, far from nose-diving like the USA, European truck sales accelerated in 2007.

Registrations of heavy-duty trucks over 16 tonnes gross vehicle weight (gvw) in the European Union grew by 7.3%. The numbers for all trucks over 3.5 tonnes gvw were up by 5.1%. European truck manufacturers and their component suppliers could not keep pace with this unexpected demand, so truck delivery lead times stretched out for a year or so and the order backlog grew. Trailer manufacturers were also caught up in the buying frenzy, their output limited mainly by availability of axles. Most truck manufacturers had anticipated European truck sales remaining broadly stable, with a decline in western Europe balancing growth in eastern Europe. In reality, 2007 delivered exceptionally strong growth in eastern Europe and moderate growth in most western Europe countries too. So what was going on in Europe and why was it so very different from the USA?

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**More fundamental than any legislation is the need to move goods. Transport is the barometer of the economy and underpins truck sales on both sides of the Atlantic.**

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European truck buyers are less wary of new technology than their USA counterparts. Consequently the pull-forward of purchasing plans ahead of tough new emissions standards in Europe is less marked than in the USA, the decline afterwards less severe. The popularity, particularly in the UK, of fixed-cost contract hire of trucks rather than ownership is also a factor. With maintenance included, contract hire reduces the risks of new technology, guarantees residual values and softens any increases in the servicing and capital costs of new, cleaner trucks. The availability of government incentives in some parts of Europe to buy even cleaner Euro V trucks, already widely available in 2007, undoubtedly helped increase sales too.

More fundamental than any legislation is the need to move goods. Transport is the barometer of the economy and underpins truck sales on both sides of the Atlantic. So it comes as no surprise to learn that growth in USA gross domestic product (GDP) in 2007 was the lowest for five years and the economic mood was decidedly downbeat. Now look at Europe and in particular the eastern European countries whose economies are powering ahead since they joined the EU in 2004. Poland's

GDP grew by 6.5% last year and its hauliers are now to be found right across the continent as Poland does business with Europe. Not surprisingly, Polish heavy-duty truck registrations rocketed by 69% last year, pushing up the EU total by almost 3% on their own. This correlation with economic growth is repeated in the truck sales of the other new EU states and elsewhere too. For example, Spanish truck sales were among the strongest in western Europe in 2007, on the back of healthy GDP growth of almost 4%.

In a generally positive European picture, UK heavy-duty truck registrations suffered badly and were the worst for a decade. However, there is no doubt that the total was depressed by delays in the deliveries of new trucks. The UK government's procrastination over the availability of Euro V vehicle incentives delayed purchasing decisions and UK operators seemed to end up towards the back of the queue as European truck plants worked at full stretch. Sure enough, new trucks started to arrive in big numbers in the UK early in 2008, with first quarter registrations of all trucks over 3.5 tonnes gvw up by 44% and tractor unit numbers up by 90% on the first quarter of 2007.

This carry over of 2007 orders into 2008 deliveries will skew the 2008 registration figures but how will the underlying European truck market perform this year? Will the surge in eastern Europe run out of steam? Will forecasts of slowing GDP growth in big European markets like Germany and the UK spoil things in western Europe? Truck manufacturers are far from gloomy. Some industry experts estimate that the truck market in Europe will grow by between 5-10%, with the industry's delivery capacity as the limiting factor. During the first two months of 2008, registrations of trucks over 16 tonnes gvw in eastern Europe grew by a further 10% and the numbers in western Europe are even stronger, up by 23%. The supply side is establishing the size of the market.

In short, European truck manufacturers expect to look back on yet another healthy set of truck sales figures come the end of 2008.



**Registrations of new trucks over 16 tonnes gvw in the European Union (Source: ACEA 2007)**

Country	2006	2007	Change (%)
Austria	6,893	7,555	9.6
Belgium	7,800	9,340	19.7
Cyprus	n/a	n/a	n/a
Czech Republic	6,699	8,217	22.7
Denmark	5,219	6,074	16.4
Estonia	1,380	1,644	19.1
Finland	2,743	2,749	0.2
France	43,613	44,405	1.8
Germany	62,682	68,420	9.2
Greece	1,247	1,417	13.6
Hungary	n/a	n/a	n/a
Ireland	3,740	3,519	-5.9
Italy	25,930	26,226	1.1
Latvia	1,949	2,813	44.3
Lithuania	2,893	4,679	61.7
Luxembourg	1,265	1,508	19.2
Malta	n/a	n/a	n/a
Netherlands	17,043	14,745	-13.5
Poland	11,361	19,237	69.3
Portugal	4,082	4,247	4.0
Slovakia	3,354	4,289	27.9
Slovenia	1,679	2,326	38.5
Spain	32,675	35,971	10.1
Sweden	5,297	5,861	10.6
United Kingdom	34,532	29,569	-14.4
<b>EU TOTAL</b>	<b>284,076</b>	<b>304,811</b>	<b>7.3</b>

EUROPEAN  
Truck Market

# Smart Thinking Behind the Latest Holset VGT™ Actuators

Written by Jeff Carter; Technical Advisor, Electrical and Electronics

**It is ten years since the introduction of the first Holset VGT™. Jeff Carter describes how development work has continued to refine Holset VGT control.**

When Cummins Turbo Technologies introduced the first Holset VGT back in 1998 the variation in the turbocharger's geometry was achieved by pneumatic actuation. The pneumatic actuator is a sealed cylinder fed by pressurised air. Several linkages connect the piston inside the cylinder to the turbocharger's nozzle, so changes in the air pressure within the cylinder will adjust the position of the nozzle (Figure 1). Changing the nozzle position affects the turbocharger's performance and this can be detected by measuring parameters such as turbocharger speed, boost pressure and exhaust manifold pressure. A key point of this arrangement is that nozzle position is not measured and so the control of the pneumatic actuator is somewhat indirect; the pressure in the actuator is adjusted by the engine control system until the desired boost pressure or other output parameter is achieved.

Pneumatic actuation has some drawbacks. It needs a supply of pressurised air because vacuum pressure is insufficient for the forces required. It also needs an air pressure control valve and associated piping. Neither is the actuation quite as swift as we would like because there is some delay or 'dead time' while the cylinder is being filled or exhausted of air. Finally, the pneumatic cylinder can only push, not pull and this can lead to instability if the system's force versus position characteristic has both positive and negative gradients.

## Electric actuation

The search for ways of overcoming these drawbacks led Cummins Turbo Technologies in 2002 to launch

a Holset VGT with an electric actuator. This uses a brushed direct current (DC) motor working through gears and a linkage to position the nozzle (Figure 2). Unlike the pneumatic system, the nozzle's position is measured directly, using a potentiometer. The position signal is sent to the engine control unit (ECU) and used to control the current being fed to the motor. There are no electronics in the actuator; the engine's ECU controls the system. This leads to the actuator being described as a 'dumb' actuator. One of the problems of the dumb actuator is that it requires specific electronic drive circuitry in the ECU, restricting the range of engines to which it can be applied. The issue of wear in the brushed motor and potentiometer means that the dumb actuator may not be suitable in the most arduous applications.

Further development of the principle of electric actuation saw Cummins Turbo Technologies in 2005 launch Holset VGT with 'smart' electric actuators. Two variants have been developed, one for the high volume and modest torque requirements of pick-up trucks (Figure 3), the other for a variety of mid-range and heavy-duty applications (Figure 4). The smart actuator features a brushless motor and determines its position by counting the number of steps the motor has moved from a reference position. The use of a brushless motor and elimination of the potentiometer removes the issue of wear already mentioned. Gears and a linkage are still used to match the motor's torque to the nozzle load.

The smart actuator is so-called because it has its own control electronics, continually adjusting the current to the motor until the measured position meets the commanded position (Figure 5). As this position adjustment can be carried out at a faster rate than the rate of change of position command from the ECU, the actuator's transient response is better than previous forms of variable nozzle control. The smart actuator can also detect and communicate if it is not performing as expected. For example, if the actuator position does not meet the command value, if the supply voltage is not in the correct range or if the internal electronics has suffered some problem then the smart actuator will know. This self-diagnostic capability forms part of the on-board diagnostics (OBD) required by future emissions



Fig 1 - Holset HY40V with pneumatic actuator



Fig 2 - Holset HE341Ve with 1st generation electric actuator





Fig 3 - Holset HE351Ve



Fig 4 - Holset HE551Ve



Fig 5 - Heavy-duty smart actuator

legislation and assists Service Engineers with their work (see article on pages 9 and 10).

### CAN-bus communication

The smart actuator receives its position command via the controller area network, commonly called the CAN-bus. This is a pair of wires that are twisted together. The signal on the bus is encoded as the difference between the voltages in the two wires. This makes the CAN-bus resilient to electromagnetic interference because common-mode interference raises the voltage in both wires by the same amount, so the difference between them is preserved. Many electronic control units may be connected to a single CAN-bus, so the bus hugely reduces the amount of wiring on an engine or vehicle (Figure 6). Of course, only one control unit can speak (transmit an electronic message) at any one time. The CAN-bus uses a system known as arbitration that prioritises transmissions, preventing multiple ECUs talking at the same time. The Holset VGT actuator also uses the CAN-bus to send information back to the ECU.

Cummins Turbo Technologies has devised special CAN messages to communicate parameters that are useful in developing smart actuators. These include information about temperature, motor drive, operating state, diagnostic code, position commanded and position achieved. We have also developed a way of recording an event log, a record of significant events in the actuator's life. Software tools running on a laptop allow development engineers and service technicians to read information from the CAN-bus. Cummins Turbo Technologies has developed its own such tool, called Holset Aspect™ to simplify

the task of communicating with the actuator. The combination of Holset Aspect and the actuator's bespoke CAN messages has been invaluable in developing and approving the actuator for use in a wide range of applications (Figures 7).

In addition to the pair of CAN-bus wires, there are two other wires (positive and ground) going to the smart actuator, supplying its electrical power. The current level is not controlled by the ECU but power may be routed through the ECU in order to isolate the actuator when the engine is switched off. Alternatively, power may be supplied to the actuator via a relay that is de-energised by the ECU when the ignition is turned off.

The smart electric actuator has been an undoubted success in terms of its dynamic transient response and its ability to operate without a supply of pressurised air, opening up the range of applications for the Holset VGT. Development of the smart actuator has been a steep learning curve and work is underway at Cummins Turbo Technologies to bring the following benefits in the future:

- Reduced package size
- Increased temperature capability
- Greater force capability
- Improved resolution
- Re-programmable software
- Sleep mode

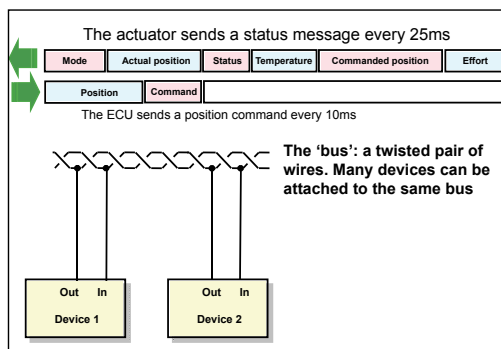


Fig 6 - CAN-bus

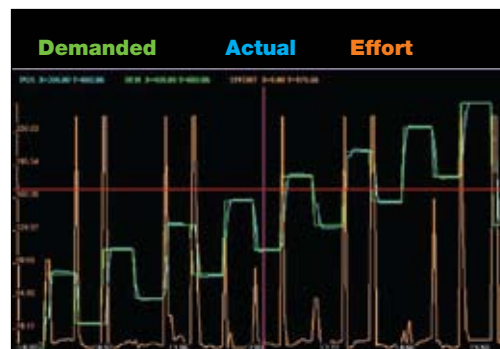


Fig 7 - Response test in Holset Aspect



# Turbocharger Service Diagnostics in the Electronic Age

Written by Keith Dewhirst;  
Leader, Worldwide Service Engineering

**The electric actuator on the Holset VGT™ is transforming fault diagnosis of returned in-service turbochargers. Where we once looked for evidence of broken metal we now interrogate the actuator.**

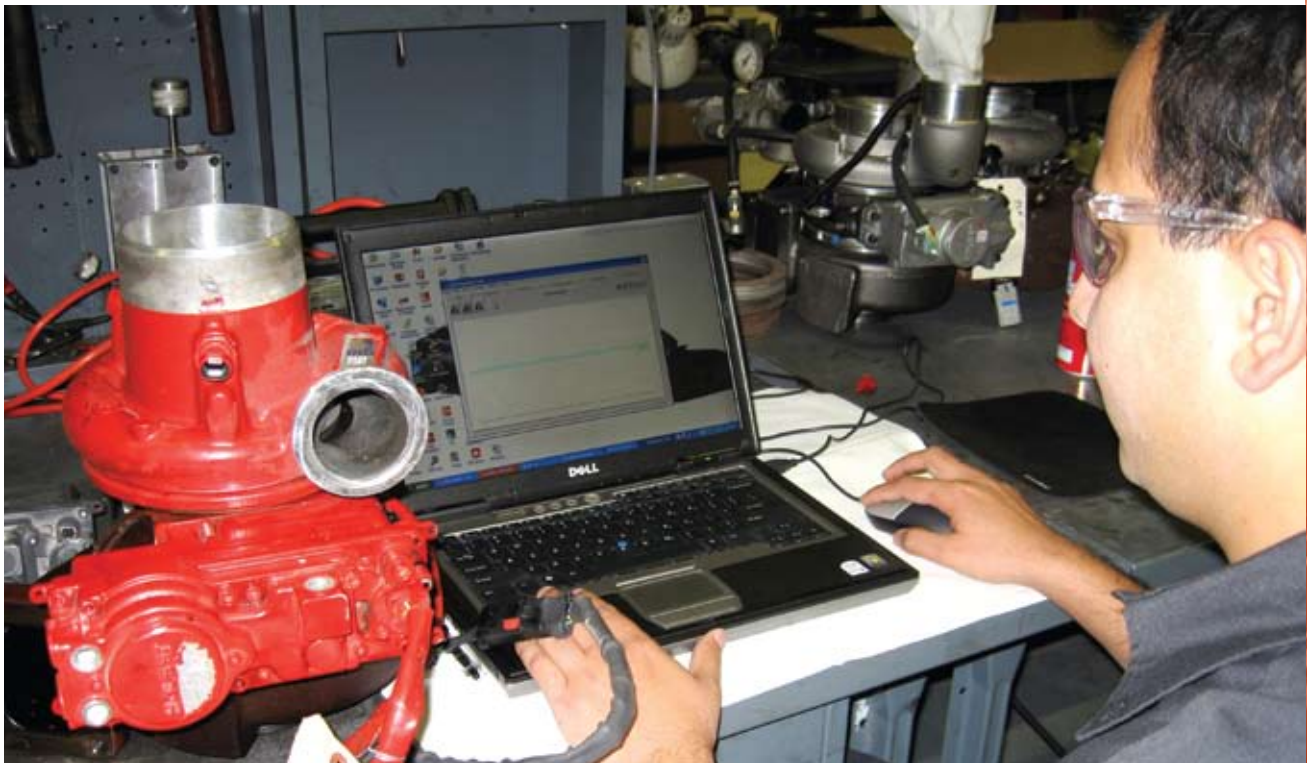
Service Engineers at Cummins Turbo Technologies are the 'private detectives' of the turbocharger world. A key part of their work is examining turbochargers considered by customers to be faulty, attempting to diagnose problems and establish how and why they occurred. However, that is particularly difficult when all they have to examine is the turbocharger and not the whole engine and vehicle to which it was originally attached. If only the turbocharger could talk.

Their wishes have been granted, thanks to the arrival of 'smart' Second Generation Electric Actuators (SGEA). This family of actuators, fitted to the most recent examples of Holset VGT, has an inbuilt ability to communicate. It has its own microprocessor and memory, capable of storing a great deal of information on-board. Integrated into each actuator are sensors for position and temperature, a clock and functions to measure voltage and current. The memory stores the original positions of the actuator's end-stops, plus any subsequent variations in those positions. Each actuator also memorises critical events that affect it during its lifetime.

To ensure that all this information can be extracted and used to best advantage, Cummins Turbo Technologies developed a computer programme able to ask an actuator all the right questions and help Service Engineers interpret the answers.

The programme, written by Calvin Cox; Actuation and Software Engineer from our Mechatronics Group, is called Holset Aspect™ and is the Cummins Turbo Technologies service diagnostic tool for these electronic actuators. Connecting a personal computer via a suitable CAN-bus (Controller Area Network) interface, a Service Engineer can use Holset Aspect to talk things over with an actuator.





*Arnab Banerjee; Service Engineer, using Holset Aspect to talk to the actuator*

**This is information technology in its purest form, with technology delivering valuable information.**

The conversation goes something like this:

Engineer: "How's it been going lately?"

Actuator: "Well, I've run into a few problems. Take a look at the last 400 significant things that happened to me."

The actuator downloads its event log to the engineer's computer.

Engineer: "It looks like you have been having problems moving the nozzle back and forth. Can you show me where?"

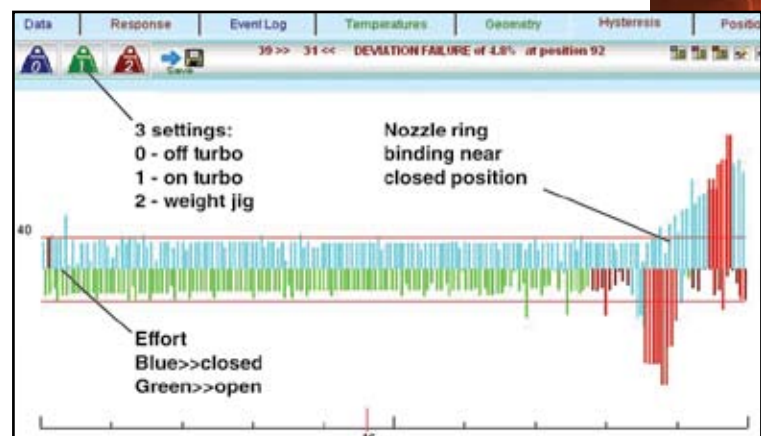
Actuator: "Yes, lately it has been getting harder to move the nozzle. Take a look at these results."

The actuator runs a hysteresis test, sweeping across its full travel in both directions and measuring its load as it goes. It then plots the results on a chart.

The Service Engineer can ask many more questions and run other tests to help understand exactly why an actuator or complete turbocharger was returned to us labelled as defective.

This is information technology in its purest form, with technology delivering valuable information. This information is power for Cummins Turbo Technologies, the power to determine whether or not there was a problem in the actuator or the turbocharger. We can pinpoint the defect and work to prevent it recurring.

In many instances the information allows us to establish that there was, in fact, no fault with the turbocharger and that the vehicle technician did not need to replace it. Problems elsewhere in an engine are sometimes wrongly assumed to lie in the turbocharger.



*Example of the hysteresis test results page from the Holset Aspect programme*

The architecture of a modern diesel engine is becoming increasingly sophisticated. Electronic fuel injection systems, exhaust gas recirculation flow control valves and exhaust after-treatment devices are all interacting with each other. When the scenario becomes so complex, every technician and engineer maintaining, repairing and providing service support needs all the help they can get. Cummins Turbo Technologies has Holset Aspect.

# Engines That Slow as Well as Go

Written by Henry Tennant; Senior Technical Advisor, Engine Air Systems

**A little extra engineering can turn a vehicle's engine into a powerful brake, lightening the workload of the wheel brakes. There are several ways of doing this and the Holset VGT™ has a contribution to make.**

When you take your foot off a car's accelerator pedal you expect the car to slow down. If the car has a diesel engine there is less engine braking than with a petrol engine because diesels generally have no throttle valve in the intake, which closes when fuel is cut off. In a heavy-duty truck there is even less retardation because a heavier vehicle has more inertia. This places more demand on the wheel brakes.

There are several circumstances in which it is useful to have a high degree of engine braking, reducing the use of the wheel brakes. For example, continuous use of the wheel brakes during long steep descents potentially leads to brake fade due to the heat generated. Drivers of vehicles that have to make frequent stops will appreciate more engine braking under deceleration. There is a legal safety requirement in Europe for petrol tankers and other vehicles carrying hazardous loads to have a secondary braking system in case of failure of the wheel brakes.

**The Holset VGT offers an extra benefit to engines with cylinder decompression braking by increasing the work done during the compression stroke.**

There are several ways of providing this secondary braking power. These fall into two categories; retarders and engine brakes.

Retarders are hydraulic pumps or electric generators installed in the drivetrain, either in the gearbox or attached to the propeller shaft. They absorb power in order to create a braking torque when activated.

An engine brake generates a braking torque by acting on the pistons during deceleration. It increases the energy needed to turn over the engine, quickly reducing engine speed and so slowing the vehicle.

## Exhaust-mounted engine brakes

The simplest form of engine brake is a butterfly valve or gate valve located in the exhaust system after the turbocharger. When closed it generates back pressure in the engine's exhaust manifold, which pressurises the cylinders during the exhaust (upward) stroke. The additional work done on the piston creates a braking torque.

This type of basic exhaust-mounted brake valve has a leakage path that limits the maximum pressure generated. This is crucial because if the pressure is too high against the back of the engine's exhaust valves they can be held open and could be struck by the pistons at top dead centre. The provision of a simple leakage hole in the exhaust brake valve does, however, reduce its braking effect at low engine speeds, so some brake valves have pressure regulating devices that allow high brake torque even at low engine speeds.

## Cylinder decompression braking

A large amount of brake torque also can be extracted from the compression and expansion (combustion) strokes of the piston if the pressure in the cylinder can be released around top dead centre. This is called cylinder decompression braking and involves opening a valve in the cylinder, releasing the compression pressure into the exhaust manifold when the piston is close to its highest point. This release of pressure means that the work done in compressing the air on the upward piston stroke is not recovered during the downward expansion stroke. The engine is acting as an air compressor and a large torque is required to turn it over; the braking torque.

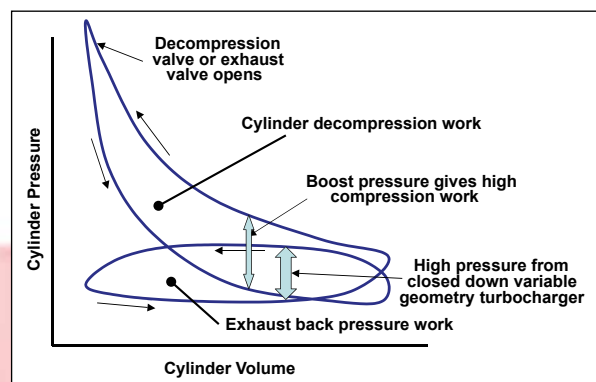


Fig 1 - How the braking power is produced

Cylinder decompression braking entails either adding a decompression brake valve in the cylinder or momentarily re-opening the exhaust valves before they would open in the normal four-stroke cycle.

Figure 1 is a pressure-volume (p-v) diagram, showing the effects on the pressure in the cylinder where the torque generation is indicated by the area of the pressure loops in each part of the cycle. A braking loop for an exhaust back pressure system and a cylinder decompression system is shown.



It is possible to combine these systems in order to achieve both cylinder decompression and a high exhaust manifold back pressure. This means both parts of the engine cycle, the closed compression part and the open exhaust and intake part, contribute to braking torque generation. This produces very high braking power, equal to the fired mode engine power. Therefore, the driver must take care when activating a braking system with such a high torque capacity, so many systems allow the driver to select from a graduated range of braking levels.

### How to open the exhaust valves

There are several mechanisms for re-opening the exhaust valves. The well known Jacobs brake uses hydraulic actuator acting on the exhaust rocker arm or bridge piece between the exhaust valves. The actuating oil pressure is produced by a master piston, activated by a cam (sometimes the fuel cam) on the camshaft or the rocker on another cylinder, chosen because of its timing in relation to the desired valve opening.

Some engine manufacturers prefer to re-open the exhaust valve by modifying the engine's camshaft and using hydraulic tappets. This entails adding a small extra braking lobe to the exhaust valve cam (Figure 2). In normal operation this small lobe lies within the valve clearance and so has no effect. By applying the engine brake, it pressurises the tappet and takes up the clearance so that the extra lobe opens the exhaust valve. Only a small opening is necessary to relieve the cylinder pressure.

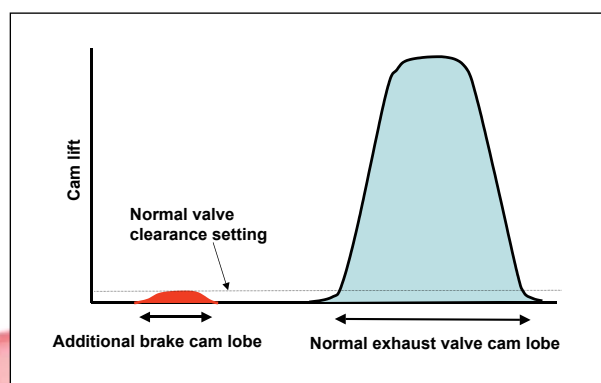


Fig 2 - Brake cam lobe

Another variation on the cam lobe method is to take up the exhaust valve clearance by rotation of an eccentrically mounted rocker shaft. On brake demand the shaft is rotated, reducing the clearance and allowing the brake lobe on the cam to open the exhaust valves (Figure 3).

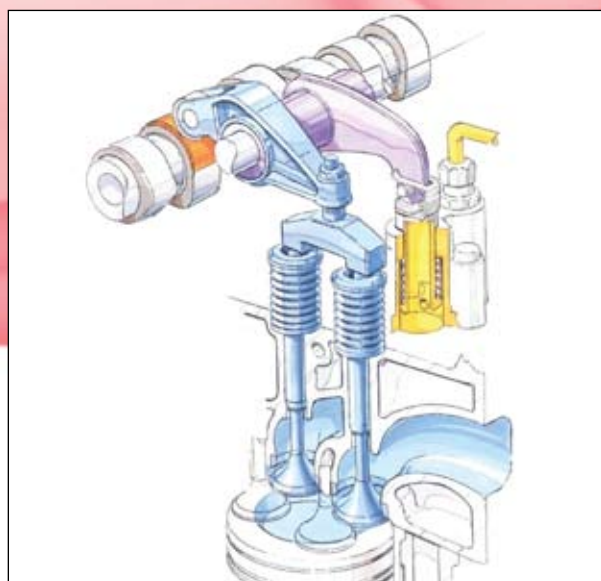


Fig 3 - Brake lobe on the cam opens the exhaust valve

### The contribution of the variable geometry turbocharger

Finally, we can look at the valuable braking contribution from the variable geometry turbocharger. Closing down the turbine nozzle during braking mode generates a back pressure in the exhaust manifold. The increase in exhaust pressure is similar to the effect of closing a butterfly valve mounted downstream in the exhaust. At high engine speeds there is sufficient airflow to over speed the turbocharger and it may be necessary to regulate the pressure or the turbocharger speed by opening up the nozzle ring gap.

The variable geometry turbocharger offers an extra benefit to engines with cylinder decompression braking. In brake mode, it provides a boost pressure that pressurises the inlet manifold. This in turn raises the cylinder pressure, increasing the work done by the engine during the compression stroke, subsequently turned into braking torque when decompression braking is activated. The negative loop area on the p-v diagram is increased, illustrating how brake torque is enhanced (Figure 1).

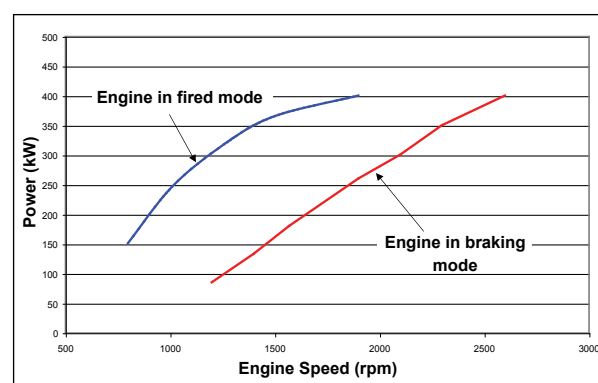


Fig 4 - Braking power compared to fired power

Figure 4 shows a comparison of the braking power and the fired mode power of a heavy-duty diesel engine fitted with a variable geometry turbocharger.

A patented feature of the Holset VGT is a method to modify the turbine efficiency during braking operation by allowing a leakage path behind the nozzle ring (Figure 5). This allows the system to be tuned to give the optimum exhaust manifold pressure and boost pressure within the speed limit of the turbocharger.

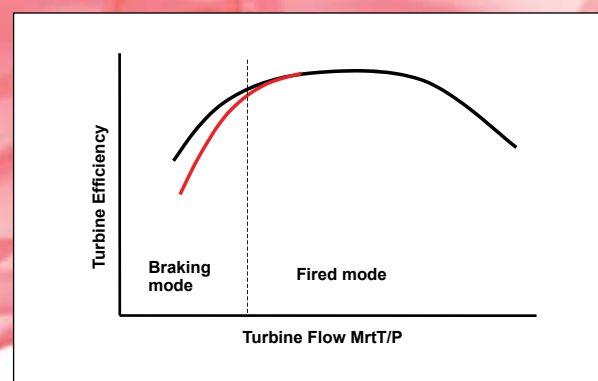


Fig 5 - Modification of Holset VGT efficiency for braking purposes

Next time you are following a bus or a truck, remember to keep your distance – it may have extremely good stopping powers thanks to these systems and the Holset VGT!



*Holset HP841 turbine inlet view*

# Axial Turbocompounding: An Alternative Route to Higher Power and Lower Emissions

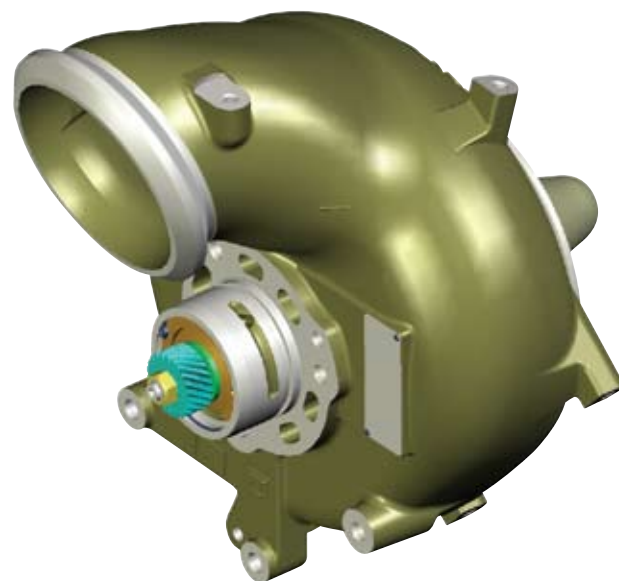
Written by Mike Dolton; Applications Manager, Europe

**The introduction of the Environmental Protection Agency (EPA) 2007 exhaust emissions legislation in the USA has seen engine manufacturers turn to advanced turbocharging techniques to meet the stringent new emission limits.**

Cutting oxides of nitrogen (NOx) to comply with the EPA 2007 standard calls for modification of the exhaust gas recirculation (EGR) technique widely adopted by USA engine manufacturers. The axial turbocompound system, developed by Cummins Turbo Technologies over the past four years, is one solution for high powered heavy-duty trucks and provides a unique alternative to the use of variable geometry or more conventional two-stage turbocharging.

The bonneted design of USA trucks suits an axial turbocompounding system as the turbocharger and power turbine are connected horizontally rather than vertically. Our system uses a Holset HX55 turbocharger coupled to a Holset HP841 power turbine. The exhaust gas leaves the turbocharger in the usual way and enters the power turbine axially, parallel to the axis of the rotor assembly. The turbine's rotation is geared down and fed to the engine's crankshaft, boosting power and torque. Only after it has given up its energy in this way is the exhaust gas expelled from the vehicle but not before it has also passed through the exhaust after-treatment system.

An engine's EGR system requires a higher pressure in the exhaust manifold than in the air inlet manifold to allow the exhaust gas to be fed back into the engine. That pressure gradient is the reverse of the ideal scenario and is detrimental to fuel consumption. Turbocompounding can compensate for that. This pressure difference is a natural effect of turbocompounding and its ability to generate up to 50hp, derived from the waste exhaust gas, means that turbocompounding increases the engine's thermal efficiency and produces a net improvement in fuel consumption.



*Holset HP841 turbine outlet and gear drive view*

Turbocompounding systems do not require the complex control systems that must be incorporated into the engine management system for variable geometry or modulated two stage turbocharging. Turbocompounding needs minimal external control to allow EGR systems to work effectively and achieve similar emission reduction objectives. In short, the well-matched Holset turbocompounding can deliver improved fuel efficiency, increased power, torque and lower emissions.



# Building Relationships with Customer Focused Six Sigma

Written by Mick Frost; Marketing Executive

**Cummins Turbo Technologies has used Six Sigma methodology for almost ten years to identify areas for improving our business processes and then implement change.**

The objective of these Six Sigma projects typically is to enhance our own efficiency by streamlining processes or cutting costs.

More recently we have increased our focus on making improvements that are especially relevant to our customers. We define any Six Sigma project that has at least one customer representative on the project team as a Customer Focused Six Sigma (CFSS) project. The primary objective of a CFSS project is to increase our customer's business success, which we hope will strengthen the relationship with Cummins Turbo Technologies.

During the last two years, we have undertaken thirty CFSS projects all over the world with original equipment manufacturers (OEMs) and with our customers in the aftermarket channel.

We identify potential new CFSS projects by running project hopper development sessions with a cross-functional group of employees in each of our locations. The sources of project ideas include:

- Improvement suggestions from recent Customer Relationship Review (CRR) interviews
- Reviewing previous successful CFSS projects to see if they can be replicated elsewhere
- Customer-related plant quality and field warranty data
- Customer-facing personnel 'brainstorming' issues and processes known to be causing customer frustration



We then prioritise the proposals that emerge from these sessions, assign a belt (project leader) and invite the customer to nominate a representative to join the project team. If our customer is prepared to commit time and resource to participate in a Six Sigma project with Cummins Turbo Technologies, this tells us that the project must be of relevance and interest to the customer.

## Examples of CFSS projects successfully completed include:

- Identifying turbocharger technology required by a major European engine OEM to meet Euro VI emissions legislation
- Reducing the throughput time at a customer's service centre in India
- Improving turbocharger delivery to a USA engine plant by better mutual planning
- Improvement in the joint turbocharger-to-engine application sign-off process with an engine OEM in China
- Introducing re-usable packaging to eliminate cardboard waste with an engine OEM in China

Successes like these demonstrate the value of Customer Focused Six Sigma and we plan to launch another thirty new projects during 2008.





**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.**