Turbo Technologies

HTi

The Latest Turbocharger News

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Executive Comments

Welcome to the thirteenth edition of HTi in which we focus on advanced design techniques. Firstly, we start with an update on our Net Promoter® Score (NPS) programme, describing how we gauge customer loyalty. I would like to thank all those who participated in the recent NPS survey; your responses help to improve what we do for all our customers.

A common theme running through all the articles on our design processes is the use of sophisticated computer modelling. Consistant with an initiative on analysis-led design, creating simulations that operate in a virtual world is very much part of today's real world. Even the design of a simple bracket to support a turbocharger's actuator is developed and optimised by modelling to ensure that it avoids resonant frequencies.

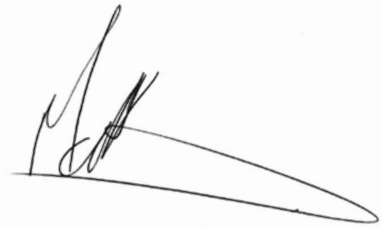
Turbochargers are subject to many sources of vibration, each of which threatens to generate unwanted noise, affect reliability or curtail component life. Our noise, vibration and harshness engineers describe how they blend simulation with real world measured data to create a hybrid model that predicts how turbochargers respond to vibrations. This is increasingly relevant because new vibration loads are emerging as manufacturers turn to the turbine housing to mount emission control components.

Simulating operation of moving components such as a variable geometry actuator mechanism calls for dynamic modelling. We explain how it contributes to the outstanding performance of the Holset VGT™ by giving very precise nozzle position control.

Mark Firth

Such is our reliance on modelling that we are upgrading our computing power to allow us to run large Computational Fluid Dynamics (CFD) studies. Modelling already cuts development times; we aim to run even more detailed and sophisticated studies and get the results even faster.

Achieving the best results more quickly is important to our customers. The article on Euro VI emissions legislation points out that although this next set of emissions limits is a few years away, the pressure is on to provide solutions ahead of the legislative deadline. Cummins Turbo Technologies is committed to working with our customers to provide turbocharging solutions for this next generation of engines.



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

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Highly Recommended:
Stimulating Growth by Improving Customer Loyalty

Written by James Moorhouse; Marketing Co-ordinator

Cummins Turbo Technologies has wasted no time in getting to grips with the results from its latest Net Promoter® Score (NPS) programme. NPS was described in more detail in issue 11 of HTi. In a nutshell, it is a simple way of understanding customer loyalty.

Raj Menon, Executive Director - Sales and Marketing discussing customer feedback with Stephen Butters - Assistant Account Manager

It is based on the principle that measuring loyalty rather than satisfaction is a better indicator of how customers really feel about their suppliers. NPS was developed by USA management consultant Fred Reichheld in conjunction with Satmetrix Systems Inc.

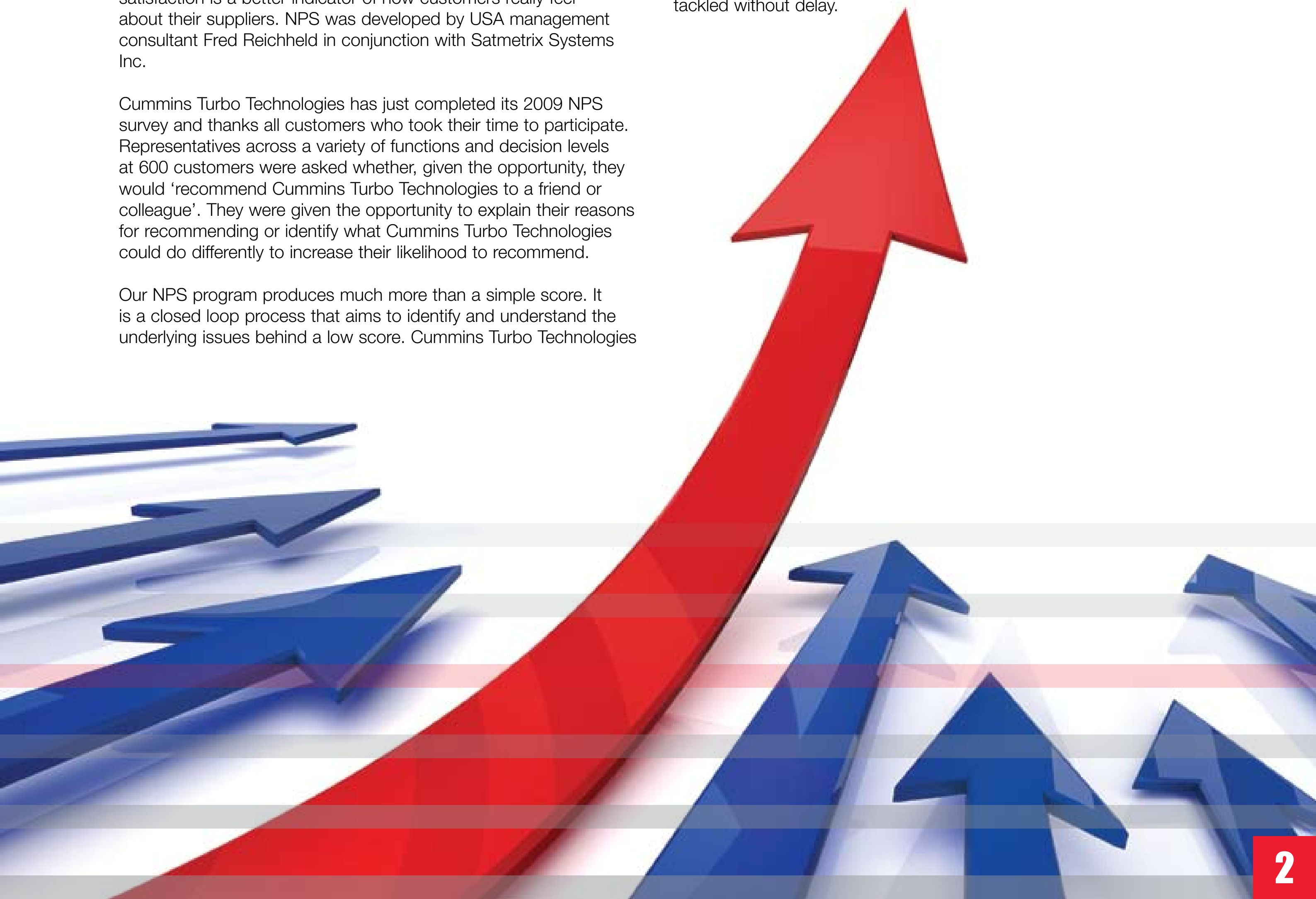
Cummins Turbo Technologies has just completed its 2009 NPS survey and thanks all customers who took their time to participate. Representatives across a variety of functions and decision levels at 600 customers were asked whether, given the opportunity, they would 'recommend Cummins Turbo Technologies to a friend or colleague'. They were given the opportunity to explain their reasons for recommending or identify what Cummins Turbo Technologies could do differently to increase their likelihood to recommend.

Our NPS program produces much more than a simple score. It is a closed loop process that aims to identify and understand the underlying issues behind a low score. Cummins Turbo Technologies is committed to following up with customers to gain a thorough understanding of their comments and to agree any immediate actions. A variety of 'just do it' fixes have already been put in place since the survey was completed in September and October, providing fast, individual responses as required.

The NPS survey also highlights some wider issues that affect multiple customers or that require action from a range of departments. Senior management from all areas of our business have begun to address these in four loyalty workshops held in China, Europe, India and North America. Loyalty workshops are a forum for detailed discussions of the customer comments and are an effective way of driving change through our processes. They provide an opportunity to analyse our NPS results at a high level, identifying trends in scores and comments.

Tools such as Six Sigma (the technique of improving overall performance by reducing variations in each process) can then be applied to issues raised by the NPS survey. Our objective is to make sure that as an organisation we develop to provide consistent best-in-class product performance, quality and customer service.

Cummins Turbo Technologies relies on customer feedback to improve as an organisation. Establishing customer loyalty instead of mere customer satisfaction underscores our determination to put the customer first, ensuring that any issues are picked up and tackled without delay.



A Model Answer:

Hybrid Vibration Analysis

**Written by Zoltan Gazdagh; Senior NVH Engineer - Applied Mechanics,
Zahir Jamil; Senior NVH Engineer - Applied Mechanics
and John M Allport; Manager - Applied Mechanics**

Lowering turbocharger vibration enhances engine performance, reliability and vehicle refinement. Vibration not only has a direct impact on durability and warranty costs but also plays an important role in the end user's perception of vehicle quality. Vibration of the turbocharger can also lead to noise, another factor likely to have a significant adverse effect on the perception of overall vehicle quality.

What is vibration analysis?

To understand the noise and vibration associated with a turbocharger installation, it is necessary either to build and test a prototype or to simulate the system using a computer model. Ideally, models are mathematical equivalents of a physical structure and closely represent reality. Vibration analyses often rely upon models that in turn are based on Computer Aided Design (CAD) models. However, some parts that make up the turbocharger assembly, such as the exhaust manifold and Exhaust Gas Recirculation (EGR) valve, are not supplied by Cummins Turbo Technologies and so their CAD models are not available. When this is the case, these components can be represented accurately in a turbocharger assembly using measurement data. This is known as hybrid modelling because it successfully blends a CAD model with real world data, in this instance vibration measurements to characterise the dynamic behaviour of the complete assembly.

Hybrid models exhibit the same characteristics as the physical components on which they are based. This hybrid technique not only overcomes the absence of CAD models of key components but also reduces computation time and simulation complexity, allowing solutions to vibration problems to be found more rapidly. There is an increasing demand from customers to use the turbocharger's turbine housing to support auxiliary components such as exhaust brakes, EGR valves and catalysts. This additional weight increases the loads placed on the turbocharger, often bringing resonances within the running speed of the engine. This can lead to other problems such as noise and increases the risk of subsequent damage to components, due to either overstressing or fatigue. Analysis techniques are important for the accurate identification of the sources, loads and locations of vibrations that will affect the turbocharger.

Using hybrid vibration analysis models

Hybrid models are used to look at the dynamic interactions of the whole assembly. Special correlation procedures have been established in house to ensure all CAD models are representative of their physical counterparts. The CAD geometry is linked to the virtual components created from test data to give a representation of the overall structure.

Figure 1 shows physical components and Figure 2 shows a hybrid model.

Fig 1 - The turbocharger assembly including the exhaust manifold

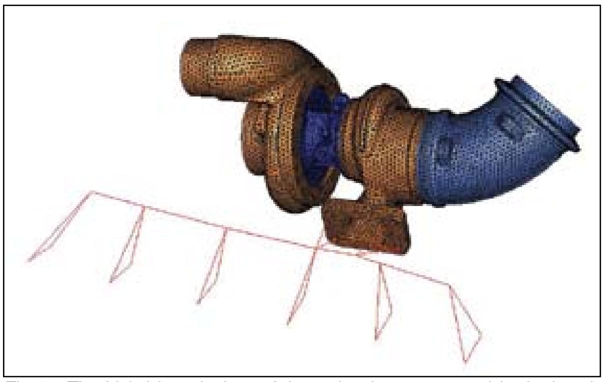


Fig 2 - The Hybrid equivalent of the turbocharger assembly depicted in Figure 1

Before CAD models can be used, they first must be converted into Finite Element (FE) models that can be taken through the modal correlation process. Modal parameters are dynamic properties of the structure including resonant frequencies, modal damping and mode shapes. Modal correlation helps to fine tune

the FE model by comparing the simulation model with vibration measurements, then tuning the modal parameters of the model until a good match is attained. This is often an iterative process. Once there is good agreement between test and simulation, the FE model can be used for vibration prediction.

Test data can also be used to define a part of the model in terms of the modal parameters if the CAD geometry is not available. A wireframe representation of the component visualises the mathematical model generated from test data. The mathematical models from both the FE model and the test data are compatible and so can be merged to create a hybrid assembly.

Many different criteria are used for assessing the quality of correlation between the model and actual vibration measurements. One method, called Modal Assurance Criterion (MAC) can be used to express the degree of similarity between the mode shapes of measured and simulated data.

An example of a MAC is shown below in Figure 3, where the X- and Y-axes represent mode shapes of the model and measured data respectively. Red boxes represent good agreement between the model and measured data, confirming that the model performs well and is ready to be used for vibration optimisation.

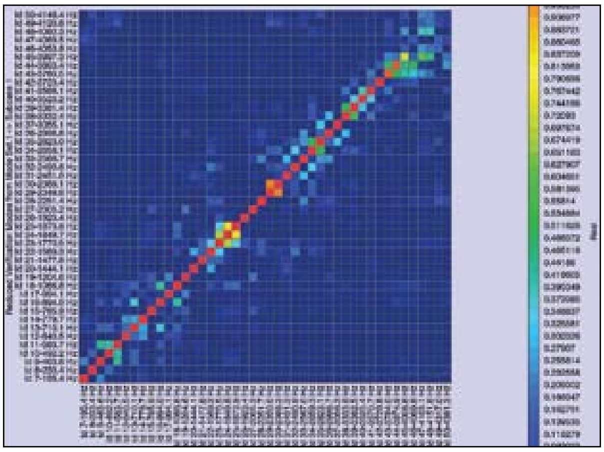


Fig 3 - An example of a Modal Assurance Criterion (MAC)

Turbochargers experience mechanical loads from a variety of sources:

- Pressure fluctuation due to combustion
- Flow induced vibration
- Airborne noise sources
- Rotor-system induced vibration
- Engine firing frequency excitation
- Static pressure due to the compressor wheel
- Temperature loads due to thermal expansion
- Static loads due to overhung masses such as exhaust brakes.

Each load contributes differently to the structure's overall vibratory response at any given point in time. This response can be calculated from:

Excitation x Dynamic Model = Computed Structural Response.

When designing a turbocharger the contributions of loads are quantified across a range of different frequencies. It is important to establish the participation of these modes at any given response frequency. When problematic mode shapes are identified, this process prioritises the load that supply excitation energy into the structure at that particular resonance frequency.

The next stage is to change the structural parameters that drive the problematic mode shapes. Vibration optimisation normally involves changes to the geometrical or material parameters. When these solutions are insufficient, we may consider the insertion of stiffening ribs, repositioning key components or adding supporting brackets. It is imperative that other modes are not adversely affected by any changes made. When there are a number of options, the most effective design variables can be quickly identified by checking the sensitivity of these parameters on the given mode shape. This optimisation can be based on vibration amplitude, resonance frequency or deflection shapes. Concentrating on the most critical parameters reduces the number of simulation runs.

Once a suitable optimum has been found, the geometry of the relevant part can be modified to match the modal parameters determined by the analysis. This means that the final product will exhibit the same characteristics as the virtual model when integrated into the completed system assembly.

Summary

Future exhaust and emission technologies mean that the turbocharger is likely to be incorporated into increasingly complex systems, leading to new vibration problems. The solution to these problems can easily be found using hybrid models. Unique modelling techniques pioneered in house at Cummins Turbo Technologies allow many scenarios to be explored in the virtual environment. These hybrid models can be used to optimise the design of turbochargers to better withstand stresses and lower the induced noise and vibration associated with mechanical loads. Designing and making components that are much more robust and resilient to vibration is a sure route to durable and reliable turbochargers.

Mapping Out the Future:
The Routes to Euro VI and Beyond

Written by Owen Ryder; Principal Engineer - Engine Air Systems

Just as one set of exhaust emissions legislation comes into force, engineers are already planning and testing the hardware for the next tier of emissions limits, even before the relevant legislation has been passed. So, while Euro V legislation became mandatory for heavy commercial vehicles first registered in the European Union from 1 October 2009, work towards Euro VI is well under way.

After 31 December 2012, new engine type approvals in Europe will have to meet the Euro VI legislation and after 31 December 2013 all new commercial vehicle engines produced for the European market will have to comply with the Euro VI limits.

The transition from Euro IV to Euro V entailed only a reduction in Nitrogen Oxides (NOx) but the move to Euro VI will be much more difficult because it calls for deep cuts in both NOx and Particulate Matter (PM). Euro VI will reduce pollutants by more than 95% when compared with the first European emissions limits, Euro I, in 1992. Figure 1 shows the huge impact of emissions legislation on the levels of pollutants emitted by diesel engines. Also bear in mind that before any emissions legislation came into force, actual emissions exceeded the limits shown in the chart.

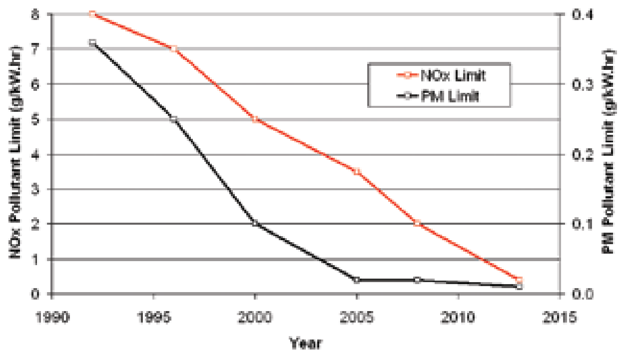


Fig 1 - Emissions reductions for European heavy-duty diesel engines

Emissions legislation has driven the choice of technologies chosen by engine manufacturers, notably the adoption of Exhaust Gas Recirculation (EGR) and exhaust after-treatment like Selective Catalytic Reduction (SCR). There have also been significant improvements to the fuel injection equipment and to the turbocharging systems, which now feature variable geometry turbochargers with electronics to communicate with the engine's computer and on-board diagnostics (OBD) system.

For Euro IV and Euro V, manufacturers have cut their engines' NOx emissions by using either EGR or SCR. There is still speculation as to whether Euro VI can be achieved with only one of these two strategies or whether a combination of EGR and SCR will be needed. The amount of EGR has a large impact on the boost pressure that the turbocharger has to supply (Figure 2), so Cummins Turbo Technologies has been working closely with engine manufacturers to understand their air supply requirements.

Image supplied courtesy of MAN

Although implementation of Euro VI is still several years away, the technology needs to be available well before then because engine manufacturers will be offering so-called ‘incentive engines’ that comply with Euro VI limits ahead of the legislation. These are likely to start appearing a couple of years before the Euro VI deadline and no doubt will be encouraged by incentives such as reductions in taxes and road tolls, as with previous emissions levels.

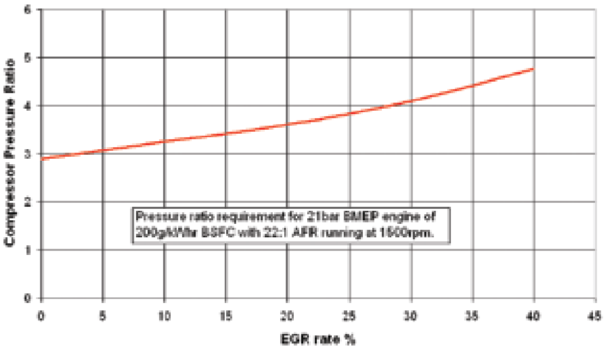


Fig 2 - Impact of EGR rates on compressor pressure ratio

With the proposal for world harmonised test cycles it seems that the different emissions legislation and test methods around the world are gradually converging on one methodology, but there is no such harmony in the technical solutions being adopted. There will always be applications or customers that prefer EGR over SCR, or vice versa and even if both EGR and SCR are required, there are different opinions about how much of each should be used. This disparity is likely to lead to an even wider range of turbocharger requirements. Low boost pressure applications using only SCR may perform satisfactorily with a wastegated turbocharger, but EGR engines or premium SCR engines will require a variable geometry turbocharger. Engines with high EGR rates will require two-stage turbocharging to reach the high boost pressures they need. All these options may be required even within one customer’s product range, so the challenges for the turbocharger manufacturer are growing, not diminishing.

Beyond Euro VI

Although there are no plans to introduce Euro VII emissions legislation, there are several related topics likely to come under the legislative eye and that need to be addressed. Fuel consumption is the major one because it is directly related to emissions of Carbon Dioxide (CO_2), the gas deemed chiefly responsible for climate change. Cummins Turbo Technologies has always placed great emphasis on producing highly efficient turbochargers and our research and development effort continues to advance this aim.

Although the engine lies at the heart of the issue, vehicle fuel efficiency improvements of the scale required by government targets cannot be met solely by improving the efficiency of engines: the whole vehicle has to become more efficient. This quest for better efficiency is likely to change the way vehicles are propelled. Sophisticated transmissions, such as continuously variable systems and hybrid drivelines that utilise energy storage seem certain to gather momentum. Each of these will bring its own challenge for the turbocharging system, whether it is a requirement for even greater efficiency, wider or narrower operating ranges, or the ability to use or provide electrical power as part of a vehicle’s energy management system. We are used to the turbocharger being part of an engine’s air-handling system but in future the turbocharger is likely to contribute to air and energy handling systems for the entire vehicle. This adds logistical, control and integration issues to the core task of supplying boost pressure.

Creating a cleaner, healthier and safer environment is one of Cummins Turbo Technologies’ vision statements and we are committed to providing technical solutions for our customers to achieve this common goal.

Differences in European commercial vehicle and passenger car legislation

European emissions legislation for heavy-duty commercial vehicles differs in several key respects from the legislation governing car exhaust emissions. Passenger cars are certified as a whole vehicle on a ‘chassis cert’ basis, with pollutants quoted in grams per kilometre (g/km). Most of the measurement points in the test-cycle are at low speeds and low loads as this is where passenger cars are operated most frequently. Passenger car emissions legislation in Europe is denoted by Arabic numbers, for example, Euro 5.

Commercial vehicles above 3.5 tonnes gvw usually have their engines certified separately on a performance dynamometer, hence the term ‘dyno cert’ engines. This allows engines to be fitted to a wide range of different vehicles without the need to certify each engine/vehicle combination. These engine specific emissions measurements therefore cannot be quoted in g/km and so the unit grams per kilowatt hour (g/kW.hr) is used instead. The legislation is referred to in Roman numerals, for example, Euro V.

A Moving Target:

Dynamic Modelling

Written by Jeff Carter; Chief Engineer - Mechatronics

In an engineering context a dynamic system is one that has energy storage and transfer. Many simple everyday objects exhibit energy transfer dynamics. For example, a swinging pendulum repeatedly transfers kinetic energy to gravitational potential energy and back again. In a turbine, thermal and kinetic energy of the exhaust gas is converted to rotational kinetic energy of the rotor system. Electrical circuits can also transfer energy, between inductors and capacitors.

What is dynamic modelling and why do we need it?

There is a range of software tools that allow engineers to build computer models of dynamic systems. Dynamic modelling improves our understanding of systems. Once the model has been characterised it can be used to study a range of design options far more rapidly and cost effectively than could be done with prototype hardware.

In this article we focus on the dynamics of the Holset VGT™ (Variable Geometry Turbocharger) nozzle, mechanism and actuator. These are all critical components because they determine the responsiveness of the turbocharger and so underpin the ability of the engine to comply with today's stringent exhaust emissions limits. The actuator also needs good transient response to prevent turbocharger over-speed.

Variable geometry actuation system

The electric actuator that moves the variable geometry nozzle in order to adjust the swallowing capacity of the turbine consists of electric motor driving gears that rotate the turbocharger's cross-shaft. This turns a yoke that produces a linear movement in the push rods and the nozzle (Figure 1).

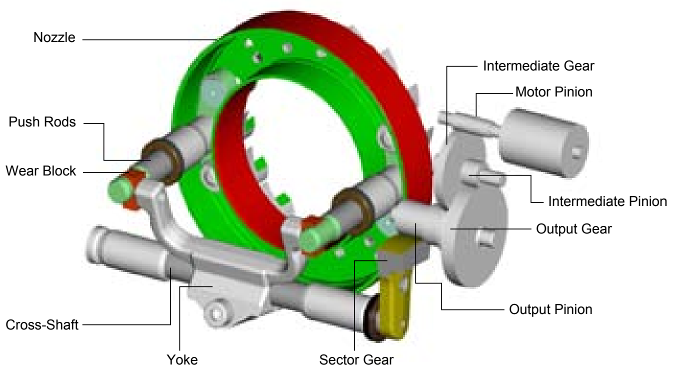


Fig 1 - Holset VGT™ actuator and mechanism

In order to design a successful actuation servo system we first need to understand the primary requirements. These include the nozzle force to be reacted, the nozzle stroke needed and the response time. Our primary design variables are motor torque and inertia, gear ratio and yoke arm length. Even with this small number of design variables and performance measures, the algebraic analysis is complex. When we include additional factors such as the non-linear and temperature dependent performance of the system, it quickly becomes apparent that we need to use a dynamic modelling tool if we are to achieve a good solution.

The dynamic modelling process

Cummins Turbo Technologies models variable geometry turbocharger actuation dynamics using a suite of tools based on Matlab and Simulink software from The MathWorks. The mechanism's geometry and other properties such as inertia can be imported from our three-dimensional Computer Aided Design (CAD) software. The modelling tools create the dynamic model as a series of interconnected blocks. Various parameters can be defined in the blocks to represent the properties of the system. The tool generates the transfer functions for each of the blocks and computes the values of the system parameters through time using the most appropriate numerical integration algorithm.

Using the models

Cummins Turbo Technologies has developed dynamic models of the actuation mechanisms used on all Holset VGT's. New designs of actuators and turbocharger mechanisms have also been modelled.

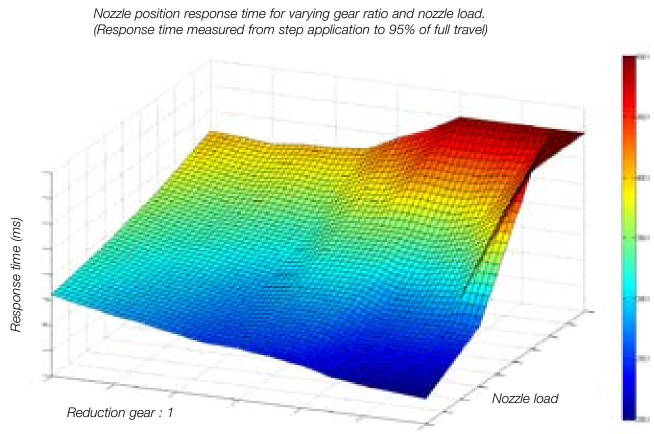


Fig 2 - Response time versus gear ratio and load

These models have been used to specify the motor torque and gear ratio of the actuator, helping us to achieve the optimum compromise between nozzle load capability, response time, actuator size and cost. Figure 2 shows the relationship between response time, load and gear ratio for a new mechanism design.

The model can also be used to develop improved schemes to control the position of the variable geometry actuator. We find that with careful optimisation, the simple proportional-integral-derivative (PID) controller is surprisingly good at handling the task of controlling the position of the variable geometry actuator. It allows the time domain performance measures to be related to critical requirements of the turbocharger and engine with relative ease. We use a number of such measures including step response rise time and overshoot, step load change position error, settling time and steady state error. The relative importance of these measures can be weighted according to the application's requirements.

Having designed the controller using the model as a test bed, an extension of the Simulink toolset can generate software code for a micro-controller. Such automatically generated code may not be as efficient as code developed by an experienced software engineer but it is produced rapidly and without coding errors. This swift prototyping process means the control algorithm can be validated as quickly as possible.

Another application for dynamic models is to study specific aspects of a mechanism's performance. A screw mechanism is attractive in that it offers a high gear ratio in a small space. However, if the nozzle runs into an end stop, the motor momentum can cause the nut to tighten on the screw, so it is advantageous to have a high torque/inertia ratio for the motor. Our models have been used to study this phenomenon and determine the torque-speed-inertia design space that guarantees that the nut can be freed from the screw (Figure 3).

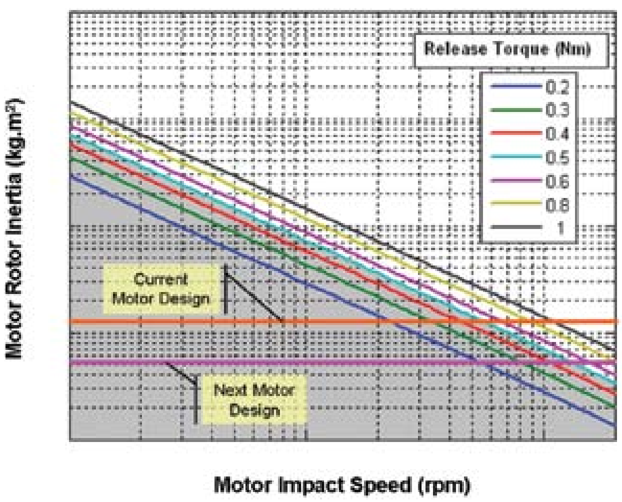


Fig 3 - Release torque

One limitation of this dynamic modelling toolset is that it performs a rigid body analysis, assuming that each component remains perfectly stiff at all times. This is significant in the analysis of impact load; if a variable geometry nozzle hits an end stop at high velocity the resulting conversion of momentum produces a high load in the mechanism. This can be modelled crudely as a rigid body mechanism with the end stop represented as a stiff spring. The spring constant can be adjusted in the model to achieve the required deceleration. The real mechanism will have some compliance in each of its components but it is very cumbersome to model the distributed compliance as a series of rigid elements connected by springs. Therefore, if deflection of components under load is relevant it may be necessary to use alternative modelling tools that incorporate finite element analysis as well as dynamic analysis.

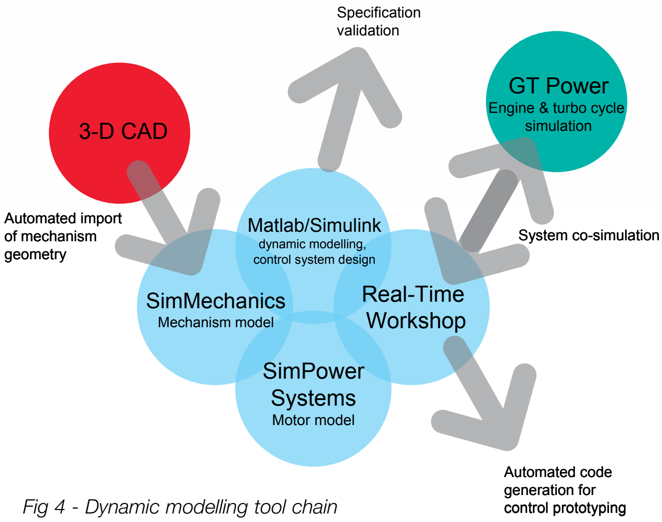


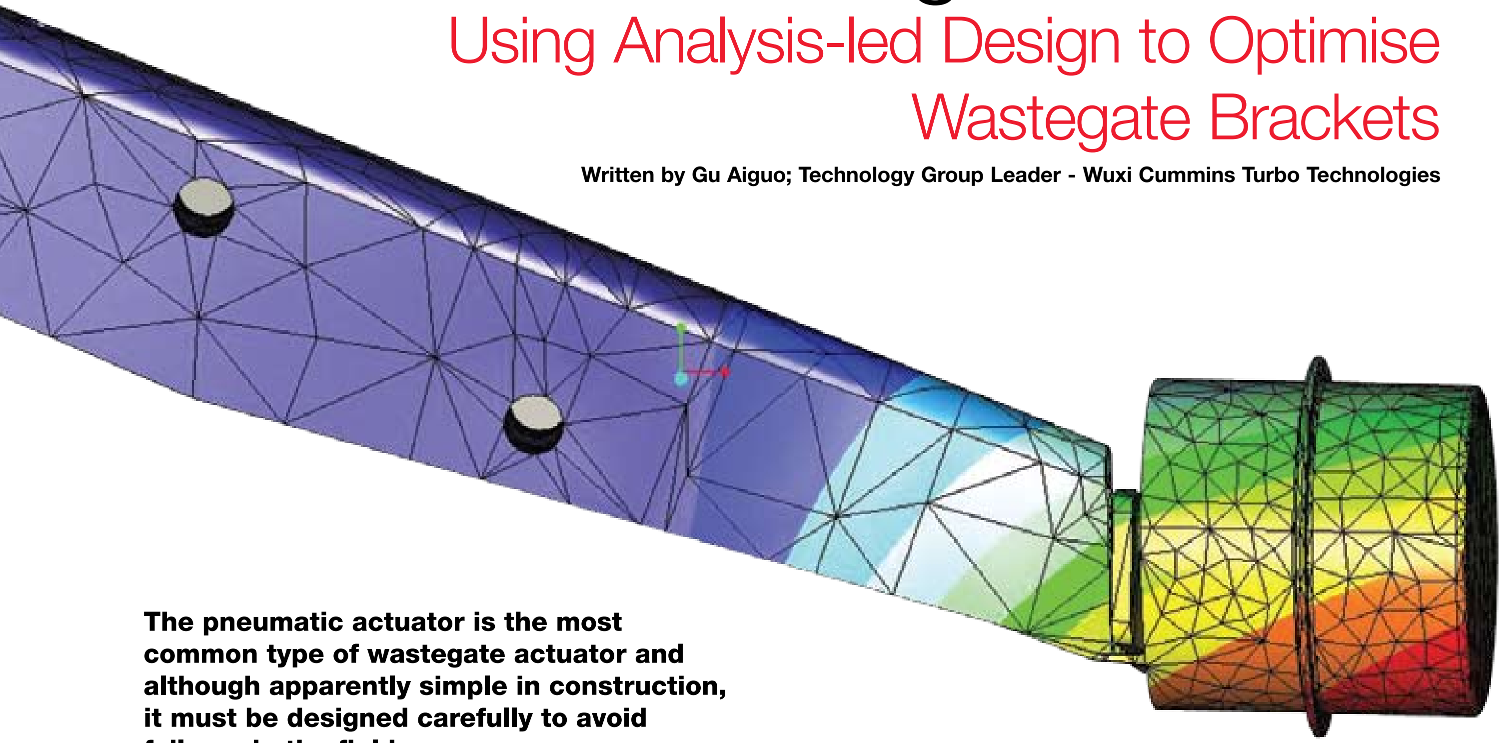
Fig 4 - Dynamic modelling tool chain

The ultimate vision for dynamic models is that they will be used to validate conformance to requirements. This means that the model will be what is described as an 'executable specification' and a formal part of Cummins Turbo Technologies' engineering development process. It will also be possible to include the dynamic model as part of the air-system analysis by linking the Simulink model with GT-Power, the engine modelling and simulation software. This will complete the analysis chain from CAD to engine performance (Figure 4).

Avoiding the Cracks:

Using Analysis-led Design to Optimise Wastegate Brackets

Written by Gu Aiguo; Technology Group Leader - Wuxi Cummins Turbo Technologies



The pneumatic actuator is the most common type of wastegate actuator and although apparently simple in construction, it must be designed carefully to avoid failures in the field.

Cummins Turbo Technologies performs many approval tests on its new actuator designs to ensure the actuator is durable in all operating conditions. However, the bracket that holds the actuator can vary from application to application due to packaging constraints. It is therefore important that a fast and accurate method of designing brackets is used that will result in a durable product.

The primary task of the actuator bracket is to support the actuator at a fixed distance from the valve that is operates. However, other requirements of the bracket mean that it is not necessarily a simple design job. The actuator bracket must also:

- Be long enough to avoid turbine temperatures above 500°C reaching the actuator but not so long that its natural frequency is too low
- Be shaped to allow assembly and actuator spring tension to be set
- Be stiff enough that resonance does not occur in the range of frequencies experienced on the engine but be simple enough to allow cost effective manufacture
- Be durable enough such that harsh engine vibrations do not cause failures.

Optimising bracket design

The brackets themselves are designed using the CAD program Pro-Engineer. The design is then transferred to Pro/Mechanica and Ansys CAE software for the prediction of natural frequencies and the stress in the bracket due to engine vibrations.

Frequency prediction analysis

The wastegate bracket's first dominant mode of vibration needs to have a frequency higher than the top dead centre event frequency of the engine. The analysis-led design allows us to design a bracket that will have the right resonant frequency before any metal is cut. The finite element analysis (FEA) model of the wastegate bracket uses beam elements to simulate bolted joints instead of bonded joints. This has reduced the error in predicted frequency by 66%.

Stress prediction

Random vibration analysis is used for stress prediction, in which the instantaneous magnitudes of the response can be specified only by probability distribution functions. Based on the test data and stress levels of previous brackets, it is now possible to achieve a one standard deviation (one sigma) stress level for new brackets subjected to the endurance test.

Endurance test

Finally, an endurance test is used to confirm the CAE analysis and that the bracket/actuator assembly will withstand the expected vibration levels.

The benefits of analysis-led design

Using these simulation methods, it is possible to study the effect of dimensional tolerances on the bracket's natural frequency and explore the best shape to achieve as high a natural frequency with the minimum material in the bracket.

The use of analysis-led design has shortened the design and validation lead time from ten to three months and the first time pass rate improved by 50%. The revised modal analysis method has significantly improved the accuracy of the natural frequency prediction such that we are confident that our actuator bracket designs will be the durable products that our customers expect from Cummins Turbo Technologies.

Go With the Flow:
Recent Advances in CFD

Written by Richard Evans; Principal Engineer - Aerodynamics

Cummins Turbo Technologies has recently upgraded its computational hardware capacity in order to run more complex and detailed simulations of fluid flow throughout the turbocharger air-handling system.

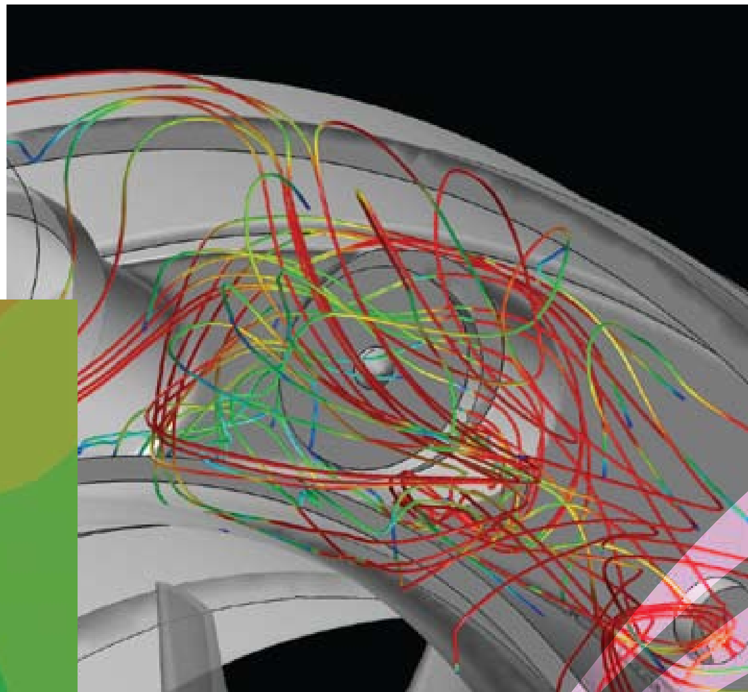
Well written Computation Fluid Dynamics (CFD) software can take advantage of the scalability of parallel computer systems. This means that a simulation run across two processors will run twice as fast as when run on a single processor. Linear scalability means that there is a consistent relationship between the number of processors and the reduction in time, so the simulation runs eight times faster on eight processors, 30 times faster on 30 processors and so on. However, by employing advanced methods with code parallelisation we can achieve what is called super-linear scalability of around 5%. This means that we go 31.5 times faster on 30 processors. Cummins Turbo Technologies currently has a parallel capacity of 64 processors, with a planned expansion to 96 in early 2010.

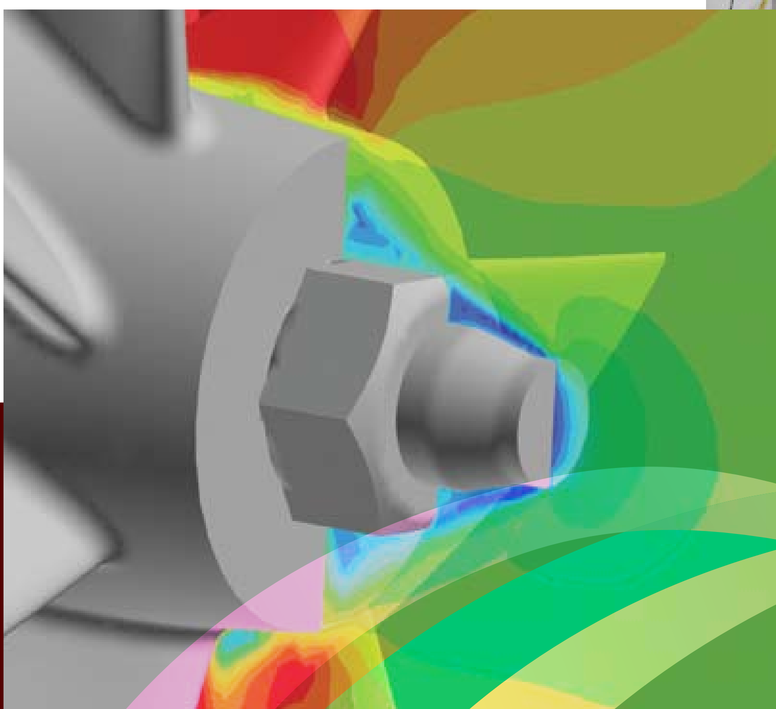
The reason we need so much computational horsepower is that we want to model the fluid flow through the turbocharger in the finest detail possible. The primary flow paths of both the compressor and turbine ends of the turbocharger are well understood and can be predicted with a simplified simulation running on a desktop computer. However, a full understanding of the flow field, including all secondary flow paths and any geometric features that have even the smallest effect on the aerodynamic performance, can only be achieved with a highly detailed resolution of all parts of the fluid domain.

CFD captures the geometric details of the fluid model by generating a volumetric mesh of interconnected polyhedral elements. Using smaller elements allows us to analyse the flow in greater detail. As we seek increasingly sophisticated and detailed design solutions it is now becoming commonplace for us to generate meshes containing in excess of 10 million cells. Generating such large meshes takes a long time and can be a significant bottleneck to the whole modelling process, so Cummins Turbo Technologies is currently working to develop new meshing techniques capable of reducing mesh generation times from hours to minutes. Our objective is also for the mesh to work directly with the native Computer Aided Design (CAD) 'metal-side' model, thus eliminating the time consuming step of creating a CAD representation of the fluid cavity.

By optimising even the smallest geometric features such as seal rings, rivet heads, corner breaks and edge treatments we can make incremental gains in performance. That performance gain can turn into a comparatively large advantage for our customers when extrapolated over the life of the product.

Simulations at this level of detail, which only a few years ago would have taken several weeks to reach a solution, are now being generated within hours. This gives engineers the confidence to make design changes knowing that the simulation will detect even the smallest and unexpected effects. Nothing is left to chance.





Cummins 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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